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USAARL REPORT NO. 69-9

EVALUATION OF THE HUMAN BODY AS AN AIRFOIL

By

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Moffett Field, California

MAY 1969

U. S. ARMY AEROMEDICAL RESEARCH LABORATORY
Fort Rucker, Alabama

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NOTATION

C_D	Drag coefficient, $\frac{D}{1/2\rho V^2 S}$
C_L	Lift coefficinet, $\frac{L}{1/2\rho V^2 S}$
L/D	Coefficient of lift to coefficient of drag ratio.
D	Drag, Pounds
L	Lift, Pounds
S	Aerodynamic reference area, feet^2
q	Dynamic pressure, pounds per foot^2
V	Test section velocity, feet per second
W	Weight
α_{act}	Actual angle of attack, measured between model reference line and test section velocity vector, degrees.
α_{nom}	Nominal angle of attack, measured between cradle reference line and test section velocity vector, degrees.
ρ	Air density, slugs per foot^3
γ	Glide path angle with respect to horizontal
$\bar{x}$	Sample mean, $\frac{\sum_{i=1}^{n} X_i}{n}$

s	Standard deviation, $\sqrt{\dfrac{n\left(\sum\limits_{i=1}^{n} X_i^2\right) - \left(\sum\limits_{i=1}^{n} X\right)^2}{n(n-1)}}$
r	Correlation coefficient
d	Honestly significant difference

ABSTRACT

Five subjects were used to determine the lift and drag characteristics of the human body held in a tracking attitude. The effects of eight different parachute pack configurations were tested to evaluate the influence of the pack upon lift and drag.

1. The mean C_L of our unencumbered subjects (0.374) corresponded to the C_L attributed to Straumann's ski-jumpers (0.43).

2. Changes in parachute pack configuration significantly changed L/D, C_L, and C_D. Subjects appeared to be homogeneous.

3. Design of a pack tray is described which, by test, had a significantly higher L/D than any currently available parachute pack tray configuration.

4. Man is not an ideal subject to test as an airfoil in the wind tunnel.

APPROVED: Robert W. Bailey

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EVALUATION OF THE HUMAN BODY AS AN AIRFOIL

INTRODUCTION

The maximum tracking attitude, as shown in Figure 1, is the body position parachutists have empirically found gives them maximum horizontal travel during free-fall (i.e., maximum lift to drag ratio). Some claim to have achieved a glide path angle as low as 55°.[1] Qualitative observations indicate that the rate of descent of the free-fall parachutist in this maximum tracking attitude is lower than the rate of descent of a free-fall parachutist in stable spread attitude (Figure 2). This is contrary to the usual situation observed in free-fall, i.e. rate of descent is inversely related to the square root of body surface area exposed to the relative wind. These qualitative observations imply that some degree of lift must be imparted to the body when it is in a tracking posture, to yield both travel and slowing of descent. Work by Straumann[5] on ski jumpers indicates that when the ski jumper is in the typical jumping position, with the body leaning forward into the relative wind, C_L for the ski jumper and his skis is 0.43. Straumann's concepts were confirmed by Tani and Miishi.[6] Oehlert and Higdon, as recently as January 1967[4], show a C_L of an anthropomorphic dummy in a "track" attitude (test configurations 31 and 32) to be about 0.30 at angles of attack where lift to drag ratios (L/D) were maximal.

Figure 3 indicates how these items integrate in a tracking parachutist. Subjective estimates indicate that the jumper is about 40° head down from the horizontal, and this would make the body chord at 15° to the relative wind, an appropriate angle of attack for a high lift configuration for most high lift airfoils. Lift and drag are imparted to the body respectively perpendicular to and parallel to its relative wind. Because of the steep glide slope the words "lift" and "drag" must be viewed purely in their aerodynamic context since, in fact, "drag" contributes more force to resist gravity than does "lift".

It appears, therefore, that lift is developed by the human body provided that the body is properly posed.

The purpose of this study was to determine the lift and drag characteristics of free-fall parachutists in a tracking attitude wearing various parachute pack configurations, using humans as test subjects. The test was conducted in the U. S. Army Aeronautical Research Laboratory 7 x 10 Foot Wind Tunnel.

MODEL DESCRIPTION

Five subjects were used in the test. All were experienced parachutists with known proficiency in tracking as demonstrated in actual free-fall. All were similarly attired in helmet, goggles, conventional jump coveralls, and boots. The subjects were tested with eight parachute pack configurations as well as with no parachute pack. The physical characteristics of the subjects are presented in Table I. The total surface area of each subject was determined from a height-weight-area nomogram.[3] The aerodynamic reference area of each subject was taken as 40% of the subject's total surface area.

Figure 4 shows the conventional B-4 main parachute back pack and reserve chest pack used by most free-fall parachutists. Due to the physical interference between the strut and the reserve chest pack, the conventional reserve chest pack could not be used in test. A simulated chest pack was fabricated which conformed in shape and volume with the chest pack reserve, but did not interfere with the strut. This simulation was used in place of the chest pack during all tests.

Figures 5 through 12 illustrate the parachute pack configurations that were tested. Table II correlates the pack configuration numbers and figure numbers, and gives a brief description of each pack configuration tested.

OPERATING PROCEDURES

The subjects were mounted in the wind tunnel on a single strut which was fitted with a specially designed cradle assembly (Figure 13) to hold the subjects. A typical installation of a subject mounted in the wind tunnel is shown in Figure 14.

The tests were conducted at a nominal dynamic pressure of 40 pounds per square foot, which corresponds to 125 mph standard day conditions. This velocity is approximately the equilibrium velocity of a freely falling parachutist near sea level conditions. In general, one run consisted of an angle of attack sweep from zero to twenty degrees or from twenty-five to fifty degrees. Measurements were taken at 5° increments. During a run, the angle of attack was remotely controlled through a pitch link mechanism. The subjects were not tested at higher angles of attack for two reasons:

1. At fifty degrees, the subject's feet were close to the tunnel floor.

2. At the higher angles of attack the subjects had a tendency to slip back in the cradle assembly. This problem would have been accentuated at higher angles of attack.

Except for a special series of runs, the subjects attempted to hold a relatively constant configuration throughout the test. During the periods when data were recorded, the subjects would bring themselves to the maximum tracking posture. This maximum tracking configuration also closely approximates the configuration which Oehlert and Higdon found to be optimum for maximum L/D and stable trim conditions.[4] Figure 14 is typical of a subject in the maximum tracking position.

Due to physical limitations, the subjects were able to hold a maximum tracking configuration for only a limited time and were allowed to relax between datum points. As a result, the subject's limb positions varied to some degree throughout each run causing a slight configuration change from datum point to datum point which could not be avoided. In addition, it was found that the subjects could not attain the same configuration in a wind-off condition as they had attained in a wind-on condition. Therefore, it was not possible to make static runs in the usual manner for pitching moment data and it was decided that the effect of shifting the model's center of gravity would be calculated rather than measured.

At each datum point six component forces and moments were measured by the wind tunnel balance system. Still photographs and movies were taken at each datum point to provide a record of the subject's positions for later analysis.

For data reduction purposes, the cradle assembly in which the subjects were mounted was considered to be part of the subject. During the early portions of the tests, a fairing protected the strut and no tares were taken from the data. For later runs, the fairing was removed and tares were removed from the data.

RESULTS OF TEST

The results of the tests are presented in Figures 15 through 26. Figures 15 through 23 present data plots of C_L, C_D, and L/D versus angle of attack for each subject and parachute pack configuration tested. The scatter in the C_L and C_D data is considerable, and this scatter is amplified when the lift-to-drag ratio i. taken.

The primary reason for the data scatter is believed to be due to the unavoidable configuration changes which occurred from datum point to datum point throughout the runs. From post-test film analysis it was discovered that the subject's limb positions could change by 20° from datum point to datum point. Surprisingly, this movement was indiscernible during testing. In addition, during the time that data was recorded at a point, it was found that the subject's limb positions (particularly the arms) would oscillate at least $\pm 10^{\circ}$. This created oscillatory loads on the balance which were not anticipated and, therefore, not accurately measured, producing the resultant data scatter.

In an attempt to smooth the data, data from selected runs were plotted against actual angle of attack rather than nominal angle of attack, after the actual angle of attack was determined from film analysis. The difference between the two angles was due to the subject lifting out of the cradle, creating a slight difference in angle of attack between the cradle and the subject. The results of accounting for this angle difference are shown in Figure 17, and it can be seen that this technique did not have any appreciable smoothing effect on the data. Consequently, it was not carried out on the remaining data.

The C_L and C_D data were finally put into bands as shown in Figures 15 through 26. A median curve was then faired through the mid-points of the data bands and from these curves the L/D ratio was calculated. These calculated points are represented by the faired curve on each of the L/D data plots.

Figure 24 presents the final data as a function of nominal angle of attack and subject number for each of the parachute pack configurations tested. Figure 25 presents the final data as a function of nominal angle of attack and pack configuration for each subject.

For comparative purposes, a short series of runs using live subjects was made in an attempt to reproduce the data obtained from an anthropomorphic dummy.[4] These data, and the configurations tested, are shown in Figure 26. Parachute pack configuration "1" was used for this series of runs since it corresponds to the pack configuration tested on the dummy. The live subjects attempted to assume the same limb positions as those at which the dummy was tested. The position assumed for the run shown in Figure 26a was the most natural position for the live subjects to take, and therefore, the easiest for them to maintain. Consequently, this data comes closest to matching the data presented in Reference 4. The remaining two configurations were not easily maintained by the subjects and their limbs oscillated more in these positions. This is the probable cause for the wider discrepancies between this data and the data of Oelhert and

Higdon. In addition, the problem of returning the limbs to the same position from datum point to datum point still existed, adding to the discrepancies between the data.

At the outset it was assumed that pitching moment data would also be obtained at each datum point. However, the problem of data scatter was even more severe with the pitching moment data than with the lift and drag data, and it was decided that there was no smoothing technique which could produce anything reliable from data which was so widely scattered. Therefore, no statement concerning the longitudinal stability of any of the configurations tested can be made.

Admitting these difficulties it still is possible to derive much useful information regarding the influence that parachute pack configuration has upon effective lift generated by the man-parachute pack aggregate.

In Table III, numerical information derived from the faired curves for each subject and pack configuration is tabulated. To develop this table a maximum L/D was selected from the faired curve, and the angle of attack at that L/D recorded. Then, the C_L and C_D at that angle of attack were recorded from their respective curves. Mean values for each of the parameters were computed for each configuration.

In Table IV, these mean values for each parachute configuration are tabulated. Means and standard deviations of these means were computed.

Observations of these data show a number of interesting comparisons with previously observed data and empirical observations.

1. The $\overline{C_L}$ of our unencumbered subjects (0.374) corresponds to the C_L attributed to Straumann's ski-jumper (0.43). The slightly lower $\overline{C_L}$ in our data may be because our subjects wore no skis.

2. Our maximum $\overline{L/D}$'s of 0.632, 0.676, and 0.700 in those parachute pack configurations most often actually jumped in free-fall (1, 3, and 5 respectively) corresponds well to the empirical estimates of glide path angle of 55° [1], since $\cot 55^\circ = 0.700 = L/D$.

3. The angle of attack of 15°, as estimated in the diagram, corresponds well with the angles of attack measured in the three above mentioned parachute pack configurations most often actually employed in free-fall of 13.8° 23.9°, and 19.9° (mean = 19.2°).

4. Comparison of Oehlert and Higdon's configuration 32 (which appears to have the closest resemblance to the maximum tracking posture assumed by our subjects), with our own information with parachute pack configuration "1", shows reasonable agreement when both sets of data are derived from their respective curves using the same method.

	Max $\overline{L/D}$	$\bar{\alpha}$ nom	$\overline{C_L}$	$\overline{C_D}$
Mean data for parachute pack configuration 1	0.632	13.8	0.33	0.52
Oehlert & Higdon's configuration 32	0.68	12°	0.28	0.40

Statistical evaluation of the parachute pack configurations 0 to 5, all of which were tested by each of our five subjects, was conducted using a randomized complete block design. Table V shows the summary tables for the analyses of variances for L/D, αnom, C_L and C_D. Parachute pack configurations are significantly different to the 0.01 level for L/D, C_L and C_D. Table VI shows the means for these parameters which proved to be significantly different to the 0.05 level using Tukey's test for honestly significant differences as described by Winer.[7]

In each case, test of packs 6, 7, and 8 was performed using only one subject. Since our analysis of variance tells us that subjects are homogeneous, it should not matter that each pack was tested by a different subject. However, since the assumption of homogeniety of variance is violated, these data were not subjected to statistical evaluation. However, the maximum L/D of pack configuration 6 is identical to that of pack configuration 5, and the maximum L/D of pack configuration 7 is identical to that of pack configuration 2. It appears by observation, therefore, that these packs offer no advantage in L/D over pack configurations 1, 2, 3, and 5. Pack 8, however, is strikingly different from all the other packs tested. The maximum L/D of 1.37 is beyond two standard deviations from the mean maximum L/D of 0.8213.

10 x 10 correlation matrices were computed comparing height, weight total body surface area, weight: body surface area ratio, and L/D ratios, C_L, and C_D for pack configurations 0 to 5. These data are presented in Table VII.

$r_{(.10)} = 0.805$ $r_{(.05)} = 0.878$ $r_{(.01)} = 0.959$ $r_{(.001)} = 0.991$

DISCUSSION

Conduct of the test permitted several subjective conclusions to be drawn.

1. It was determined that man is less than an ideal subject to test as an airfoil in a wind tunnel because:

a. He moves during tests.

b. He cannot reliably reproduce a desired attitude for repeated testing.

c. He fatigues.

2. Qualitative appraisal by successful "trackers" indicates that maintaining the posture necessary for an efficient "track" is very tiring. We were able to confirm this in the wind tunnel. The subjects, although in good physical condition, were not able to hold the necessary position against a dynamic pressure of 40 psf for more than 10 seconds at a time. They felt that this time was unusually short because of the uncomfortable cradle support and the unusual wind tunnel conditions, but agreed that in free-fall, one could not hold a tracking posture for more than one minute under ordinary circumstances.

Statistical evaluation of our data indicates that the best L/D is achieved by tracking with no parachute. Despite the desirable glide slopes, we do not advise the use of this configuration. The only L/D of a currently available parachute pack-tray assembly tested which approached the no-pack condition was that of a flat-packed Navy NB-6 assembly with no reserve. There was no significant difference between L/D's between these two configurations, but both had L/D's which were significantly higher than parachute pack configuration 1, 3, and 5; and in addition, "no pack" had an L/D significantly higher than parachute pack configuration 2. In the case of the NB-6, both C_L and C_D were increased over "no pack" figures, and the optimal angle of attack was the highest we measured for any pack configurations, 34°. In all other parachute configurations the C_L was not significantly different from the C_L for the no-pack condition, but C_D's were uniformly higher and, in the case of pack 3, 4, and 5, to beyond the 0.05 significance level. This increased drag caused the observed lower L/D's.

Inspection of the data collected upon parachute pack configurations 6 and 7 suggests that a similar mechanism applied to these configurations, i.e., a disproportionate rise in C_D with no significant increase in C_L.

The design for pack 8 was developed from theoretical information before the wind tunnel testing and refined during test. Its main features include:

1. Correct shaping to:

a. Form fit to the back.

b. Extend from shoulders to buttocks.

c. Smoothly increase the camber of the man-pack to peak at about the level of the nipples, and then smoothly decrease camber to the buttocks.

2. Correct coupling to:

a. Prevent peeling of the parachute leading edge from the shoulders.

b. Prevent air passage between pack tray and man.

3. A rigid or semi-rigid dorsal surface to prevent flutter of the upper surface of the pack tray.

The test conducted upon a simulation of this pack showed a striking increase in L/D, to more than 2 standard deviations above the $\overline{L/D}$ of all configurations tested. This was produced by an increase in C_L with no increase in C_D. This indicates that a jumper's ability to achieve horizontal travel could be markedly improved by using a properly designed pack tray and harness. Further testing in actual free-fall certainly seems advisable using a functioning harness and parachute-filled pack-tray designed to these specifications.

Several interesting extensions of the wind tunnel data collected upon this experimental configuration (8) are:

1. If such an L/D is achievable in actual free-fall, a glide slope of 36° would be anticipated.

$$\cot \gamma = L/D = 1.37, \text{ then } \gamma = 36^\circ\ 7'$$

2. Using the C_L developed by this experimental pack tray, it is possible to calculate the velocity necessary to keep a 170 pound man with

30 pounds of parachute equipment in straight and level flight at 2500' MSL.

$$v = \sqrt{\frac{W}{C_L \times \frac{\rho}{2} \times S}}$$

$$v = \sqrt{\frac{200 \text{ lbs}}{0.52 \times \frac{0.002209 \text{ slugs/cu ft}}{2} \times 8.08 \text{ sq ft}}}$$

$$\begin{aligned} v &= 207.6 \quad \text{ft/sec} \\ &= 122.9 \quad \text{kts} \\ &= 141.6 \quad \text{mph} \end{aligned}$$

It is clearly possible to achieve such velocities, and means may soon become available to maintain velocities of this level for a number of minutes. It is also known that man can tolerate velocities of this level for short periods with a minimum of protective clothing. Our tests, however, do cast some doubt upon whether man can maintain a tracking posture for such a period, and the question of aerodynamic stability during such a flight is still open.

3. In the free-fall environment parasitic drag is not uniformly undesirable. Because of the steep glide slope, the vector usually described as "drag" in airfoil diagrams is, in fact, opposing gravity for the parachutist. Any "lift" vector which exists moves him horizontally across the ground. In this context, parasitic drag reduces equilibrium velocity. On the other hand, if one wishes to flatten out the glide slope, i.e., to improve "track" or increase the L/D, then parasitic drag must be kept to a minimum. To accomplish this tight clothing are desirable, flapping of clothing and equipment must be prevented, and peeling of the pack tray away from the jumper's back must be avoided. In the wind tunnel it became obvious that when the pack tray was secure against the jumper's back, it tended to increase camber, and thereby increase lift. When peeling occurred, however, the pack tray acted as a spoiler and decreased lift and markedly increased parasitic drag.

Examination of the correlation matrices indicates the following:

1. Height relates directly to L/D's of parachute pack configurations 0 and 5.

2. Weight, total body surface area, and weight: body surface area ratio relate directly with the L/D of parachute pack configuration 3 and inversely with the L/D of pack configuration 2.

3. Comparisons of the L/D's of parachute pack configurations 1 and 3, 1 and 4, 2 and 4, and 4 and 5 relate directly.

4. Comparisons of the L/D's of parachute pack configurations 0 and 1, and 0 and 4 relate inversely.

This indicates that for any individual, it may be possible to improve his L/D by the correct selection of a currently available parachute pack tray and harness configuration, with selection based upon his height, weight, total body surface area, and weight: body surface area ratio. For example, it appears that the tall individual would track best with parachute pack configuration 5 (assuming that he'd prefer to jump with a parachute), whereas the short, heavy individual would track best with parachute pack configuration 3. It also suggests that if one can successfully track with parachute pack configuration 1, he can also probably track well with parachute pack configurations 3 and 4; and if he can successfully track with parachute pack configuration 2, he can also probably track well with parachute pack configuration 4. If he then successfully tracks with parachute pack configuration 4, he probably will be able to track well with parachute pack configuration 5. Conversely, if one tracks poorly unencumbered (and assuming he survives impact), he may best improve his L/D by using parachute configurations 1 or 4.

SUMMARY

Five subjects were used to determine the lift and drag characteristics of the human body held in a tracking attitude. The effects of eight different parachute pack configurations were tested to evaluate the influence of the pack upon lift and drag.

1. The mean C_L of our unencumbered subjects (0.374) corresponded to the C_L attributed to Straumann's ski-jumpers (0.43).

2. Changes in parachute pack configuration significantly changed L/D, C_L, and C_D. Subjects appeared to be homogeneous.

3. Design of a pack tray is described which, by test, had a significantly higher L/D than any currently available parachute pack tray configuration.

4. Man is not an ideal subject to test as an airfoil in the wind tunnel.

TABLE I

SUBJECT'S PHYSICAL CHARACTERISTICS

Subject	Height Inches	Weight Lbs	Total Surface Area, Ft^2*	Aerodynamic Reference Area, Ft^2
1	71	140	18.18	7.27
2	70	175	20.30	8.12
3	72	170	20.20	8.08
4	69	165	19.35	7.74
5	67	130	17.10	6.84
$\bar{x}$	69.8	156.0	19.026	7.610
s	1.9	19.8	1.372	0.549

* Based on nomogram from Reference 3.

TABLE II

PARACHUTE PACK CONFIGURATIONS

Pack Configuration Number	Figure Number	Description
0	None	No pack
1	4	Conventional B-4 assembly back pack, simulated chest reserve pack
2	5	Conventional B-4 assembly back pack, no reserve
3	6	Back pack with piggy-back reserve (A)
4	7	NB-6 assembly back pack, no reserve
5	8	Back pack with piggy-back reserve (B)
6	9	NB-6 assembly back pack with simulated seat pack reserve
7	10	NB-6 assembly back pack with simulated piggy-back reserve
8	11	Simulated back pack-reserve pack combination, rigid

TABLE III

Subject	Max L/D	α_{nom}	C_L	C_D
Pack configuration: (0) no pack				
1	1.15	15.0°	0.37	0.32
2	1.00	17.0°	0.35	0.35
3	0.90	10.5°	0.32	0.36
4	0.93	20.0°	0.41	0.44
5	0.81	23.0°	0.42	0.52
$\sum X$	4.79	85.5°	1.87	1.99
$\overline{X}$	0.958	17.10	0.374	0.398
s	0.127	4.77	0.041	0.081
Pack configuration: (1) B-12 with chest reserve				
1	0.50	11.0°	0.25	0.50
2	0.64	13.5°	0.29	0.45
3	0.71	21.0°	0.36	0.51
4	0.63	11.0°	0.32	0.51
5	0.68	12.5°	0.43	0.63
$\sum X$	3.16	69.0°	1.65	2.60
$\overline{X}$	0.632	13.80	0.330	0.520
s	0.080	4.16	0.068	0.066
Pack configuration: (2) B-12 no reserve				
1	0.75	14.5°	0.33	0.44
2	0.67	19.0°	0.36	0.54
3	0.78	18.5°	0.39	0.50
4	0.70	13.5°	0.31	0.44
5	0.80	21.0°	0.39	0.49
$\sum X$	3.70	86.5°	1.78	2.41
$\overline{X}$	0.740	17.30	0.356	0.482
s	0.054	3.17	0.036	0.042

TABLE III (continued)

Subject	Max L/D	α_{nom}	C_L	C_D
Pack configuration: (3) Pioneer Piggy back				
1	0.59	20.0°	0.29	0.49
2	0.66	11.5°	0.35	0.53
3	0.77	50.0°	0.49	0.64
4	0.73	19.0°	0.35	0.48
5	0.63	19.0°	0.39	0.62
ΣX	3.38	119.5°	1.87	2.76
$\overline{X}$	0.676	23.90	0.374	0.552
s	0.073	14.98	0.074	0.073
Pack configuration: (4) NB-6 main, no reserve				
1	0.79	30.0°	0.44	0.56
2	0.91	50.0°	0.51	0.56
3	0.95	13.5°	0.41	0.43
4	0.71	50.0°	0.45	0.63
5	1.02	26.5°	0.53	0.52
ΣX	4.38	170.0°	2.34	2.70
$\overline{X}$	0.876	34.00	0.468	0.540
s	0.125	15.85	0.050	0.073
Pack configuration: (5) Security Piggy-back				
1	0.72	23.5°	0.44	0.61
2	0.74	17.0°	0.35	0.47
3	0.80	20.0°	0.39	0.49
4	0.55	19.0°	0.31	0.56
5	0.69	20.0°	0.45	0.65
ΣX	3.50	99.5°	1.94	2.78
$\overline{X}$	0.700	19.90	0.388	0.556
s	0.093	2.36	0.059	0.077

TABLE III (continued)

Subject	Max L/D	α_{nom}	C_L	C_D
Pack configuration: (6) NB-6 with seat reserve				
1				
2	0.70	30.0°	0.38	0.54
3				
4				
5				
Pack configuration: (7) NB-6 with piggy-back reserve				
1				
2				
3				
4				
5	0.74	15.5°	0.44	0.59
Pack configuration: (8) Experimental design				
1	1.37	7.5°	0.52	0.38
2				
3				
4				
5				

TABLE IV

Pack Configuration	Max $\overline{L/D}$ From Curve	$\bar{\alpha}_{nom}$	$\overline{C_L}$	$\overline{C_D}$	n
(0)	0.958	17.10	0.374	0.398	5
(1)	0.632	13.80	0.330	0.520	5
(2)	0.740	17.30	0.356	0.482	5
(3)	0.676	23.90	0.374	0.552	5
(4)	0.876	34.00	0.468	0.540	5
(5)	0.700	19.90	0.388	0.556	5
(6)	0.70	30	0.38	0.54	1
(7)	0.74	15.5	0.44	0.59	1
(8)	1.37	7.5	0.52	0.38	1
$\overline{X}$	0.8213	19.889	0.4033	0.5063	
s	0.2295	8.229	0.0605	0.0729	

TABLE V

SUMMARY TABLE ANALYSIS OF VARIANCE

For L/D

	SS	DF	MS	F
Between Individuals	0.0646	4	0.0161	2.0641
Between Pack Configuration	0.3999	5	0.0799	10.2435**
Error	0.1546	20	0.0078	
Total	0.6209	29		

For α_{nom}

	SS	DF	MS	F
Between Individuals	43.7499	4	10.9375	0.1076
Between Pack Configuration	1345.5499	5	269.1099	2.6472
Error	2033.2000	20	101.6600	
Total	3422.5000	29		

TABLE V (continued)

For C_L

	SS	DF	MS	F
Between Individuals	0.0270	4	0.0068	2.6986
Between Pack Configuration	0.0547	5	0.0109	4.3682
Error	0.0501	20	0.0025	
Total	0.1318	29		

For C_D

	SS	DF	MS	F
Between Individuals	0.0332	4	0.0083	1.9485
Between Pack Configuration	0.0920	5	0.018	4.3146**
Error	0.0853	20	0.0043	
Total	0.2106	29		

TABLE VI

C_L

Pack Configuration	0	1	2	3	4	5
	0.374	0.330	0.356	0.374	0.468	0.388
0	0	0.044	0.018	0	0.094	0.014
1		0	0.026	0.044	0.138*	0.058
2			0	0.018	0.112*	0.032
3				0	0.094	0.014
4					0	0.080
5						0

d = 0.0996 at 0.05 level

C_D

Pack Configuration	0	1	2	3	4	5
	0.397	0.520	0.482	0.552	0.540	0.556
0	0	0.123	0.085	0.155*	0.143*	0.159*
1		0	0.038	0.032	0.020	0.036
2			0	0.070	0.058	0.074
3				0	0.012	0.004
4					0	0.016
5						0

d = 0.1300 at 0.05 level

C_L/C_D

Pack Configuration	0	1	2	3	4	5
	0.9580	0.6320	0.7400	0.6760	0.8760	0.700
0	0	0.326*	0.218*	0.282*	0.082	0.258*
1		0	0.108	0.044	0.244*	0.068
2			0	0.064	0.136	0.040
3				0	0.200*	0.024
4					0	0.176*
5						0

d = 0.1722 at 0.05 level

CORRELATION MATRIX FOR COEFFICIENT OF LIFT

	1	2	3	4	5	6	7	8	9	10
1 Height	1.00	0.53	0.66	0.37	-0.88*	-0.57	-0.04	0.22	-0.80	-0.10
2 Weight		1.00	0.99	0.98	-0.60	-0.31	-0.11	0.32	-0.33	-0.81
3 Surface area			1.00	0.93	-0.72	-0.37	-0.06	0.34	-0.41	-0.71
4 Weight/Surface area ratio				1.00	-0.43	-0.24	-0.18	0.28	-0.24	-0.90*
5 Pack 0					1.00	0.34	-0.31	-0.43	0.53	0.06
6 Pack 1						1.00	0.69	0.64	0.38	0.27
7 Pack 2							1.00	0.72	0.26	0.50
8 Pack 3								1.00	-0.26	-0.01
9 Pack 4									1.00	0.17
10 Pack 5										1.00

n = 5

r (.10) = 0.805
r (.05) = 0.878
r (.01) = 0.959
r (.001) = 0.991

CORRELATION MATRIX FOR COEFFICIENT OF DRAG

	1	2	3	4	5	6	7	8	9	10
1 Height	1.00	0.53	0.66	0.37	-0.90*	-0.70	0.04	-0.02	-0.40	-0.61
2 Weight		1.00	0.99	0.98	-0.46	-0.77	0.43	-0.09	-0.02	-0.95*
3 Surface area			1.00	0.93	-0.58	-0.81	0.43	-0.06	-0.12	-0.97**
4 Weight/Surface area ratio				1.00	-0.30	-0.70	0.37	-0.15	0.11	-0.88*
5 Pack 0					1.00	0.84	-0.07	0.30	0.15	0.57
6 Pack 1						1.00	-0.18	0.51	-0.19	0.78
7 Pack 2							1.00	0.51	-0.44	-0.59
8 Pack 3								1.00	-0.88*	-0.04
9 Pack 4									1.00	0.23
10 Pack 5										1.00

$n = 5$

$r(.10) = 0.805$
$r(.05) = 0.878$
$r(.01) = 0.959$
$r(.001) = 0.991$

CORRELATION MATRIX FOR COEFFICIENT OF LIFT TO COEFFICIENT OF DRAG RATIO

	1	2	3	4	5	6	7	8	9	10
1 Height	1.00	0.53	0.66	0.37	0.56	-0.18	-0.11	0.33	-0.20	0.56
2 Weight		1.00	0.99**	0.98**	0.05	0.33	-0.65	0.70	-0.21	0.10
3 Surface area			1.00	0.93*	0.14	0.27	-0.59	0.67	-0.18	0.24
4 Weight/Surface area ratio				1.00	-0.04	0.37	-0.70	0.72	-0.27	-0.07
5 Pack 0					1.00	-0.88*	-0.39	-0.45	-0.56	0.11
6 Pack 1						1.00	0.24	0.69	0.61	0.18
7 Pack 2							1.00	-0.05	0.55	0.34
8 Pack 3								1.00	-0.04	-0.01
9 Pack 4									1.00	0.66
10 Pack 5										1.00

$n = 5$

$r(.10) = 0.805$
$r(.05) = 0.878$
$r(.01) = 0.959$
$r(.001) = 0.991$

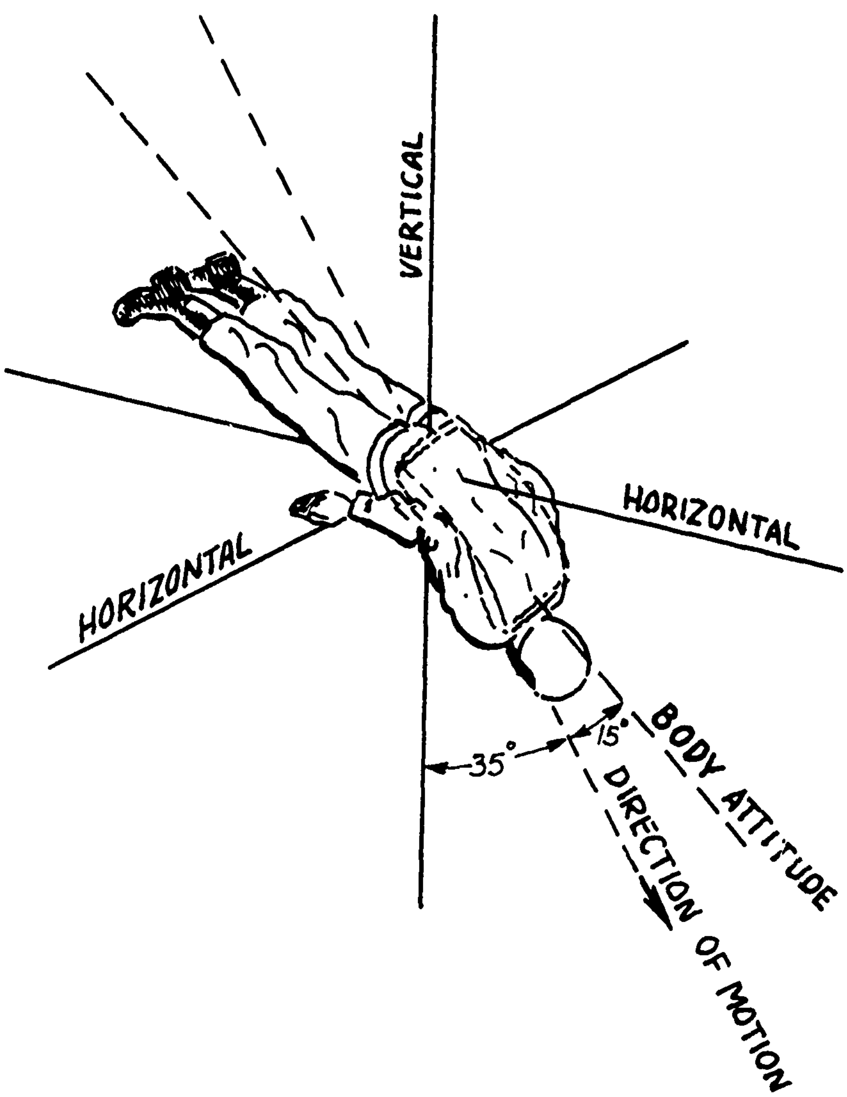

VERTICAL
HORIZONTAL
HORIZONTAL
35°
15°
BODY ATTITUDE
DIRECTION OF MOTION

Figure 1

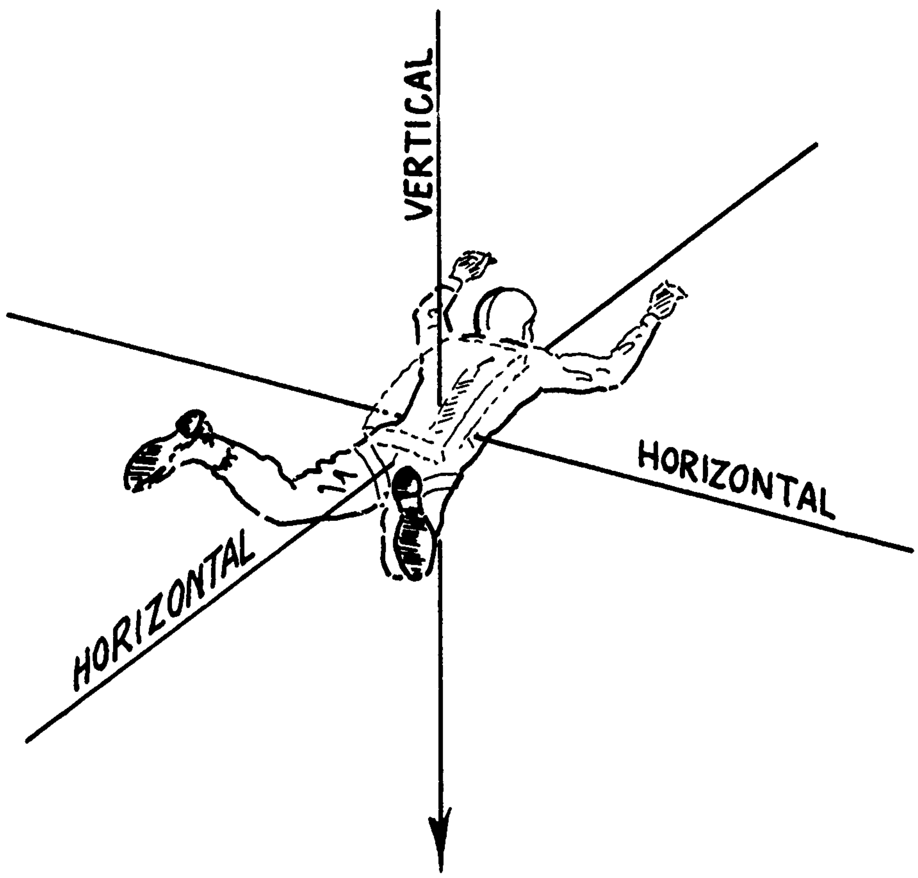


Figure 2

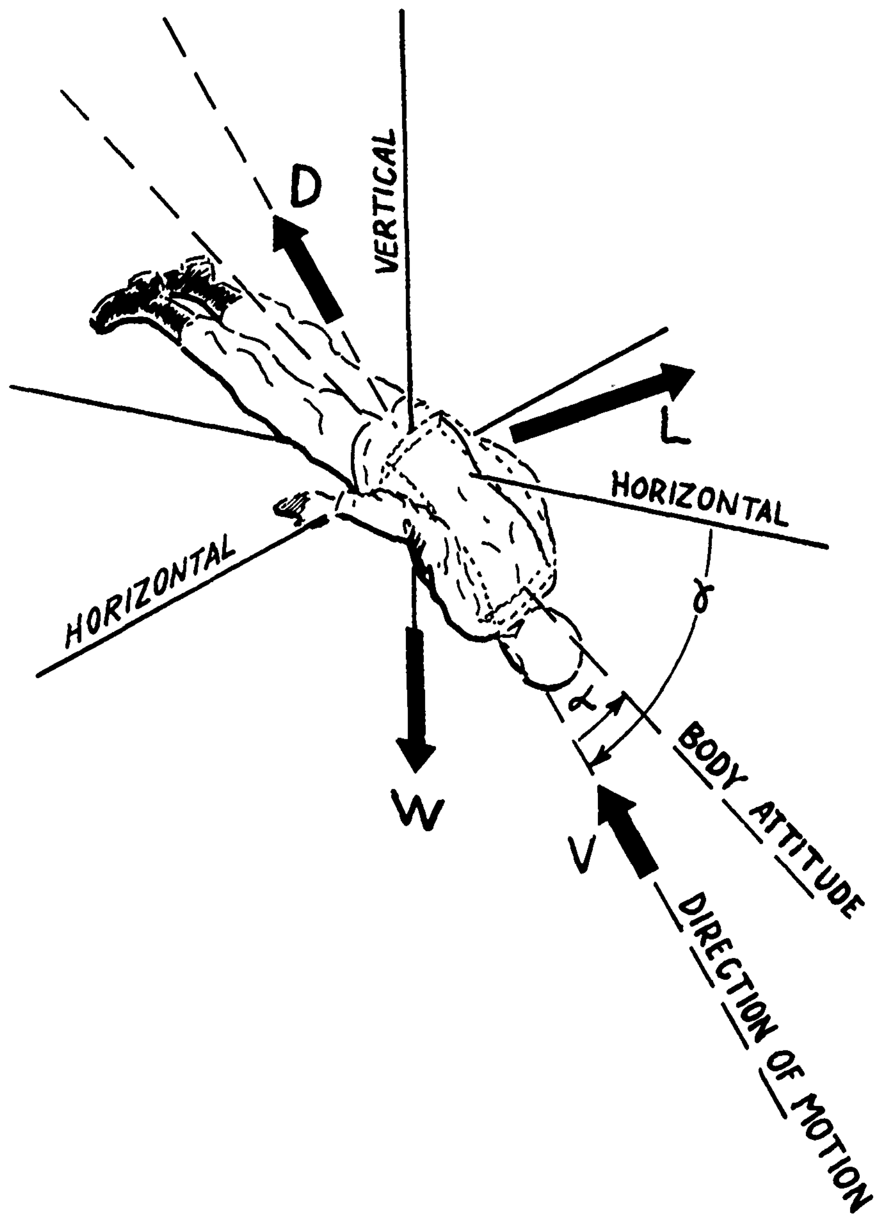

D
VERTICAL
L
HORIZONTAL
HORIZONTAL
γ
α
W
V
BODY ATTITUDE
DIRECTION OF MOTION

Figure 3

Figure 4. Conventional Main Parachute Back Pack and Reserve Chest Pack Configuration - Subject No. 1

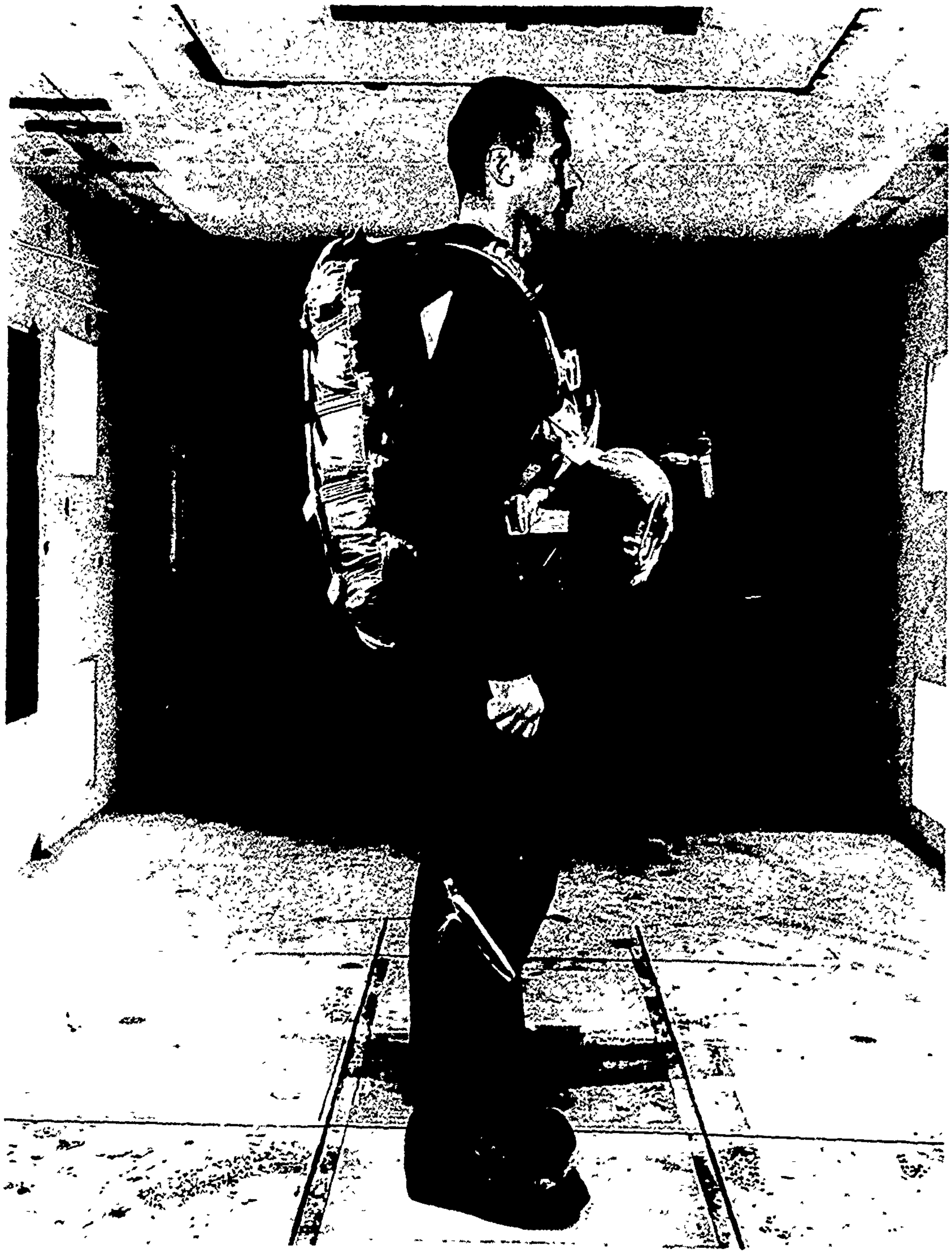


Figure 4. Concluded

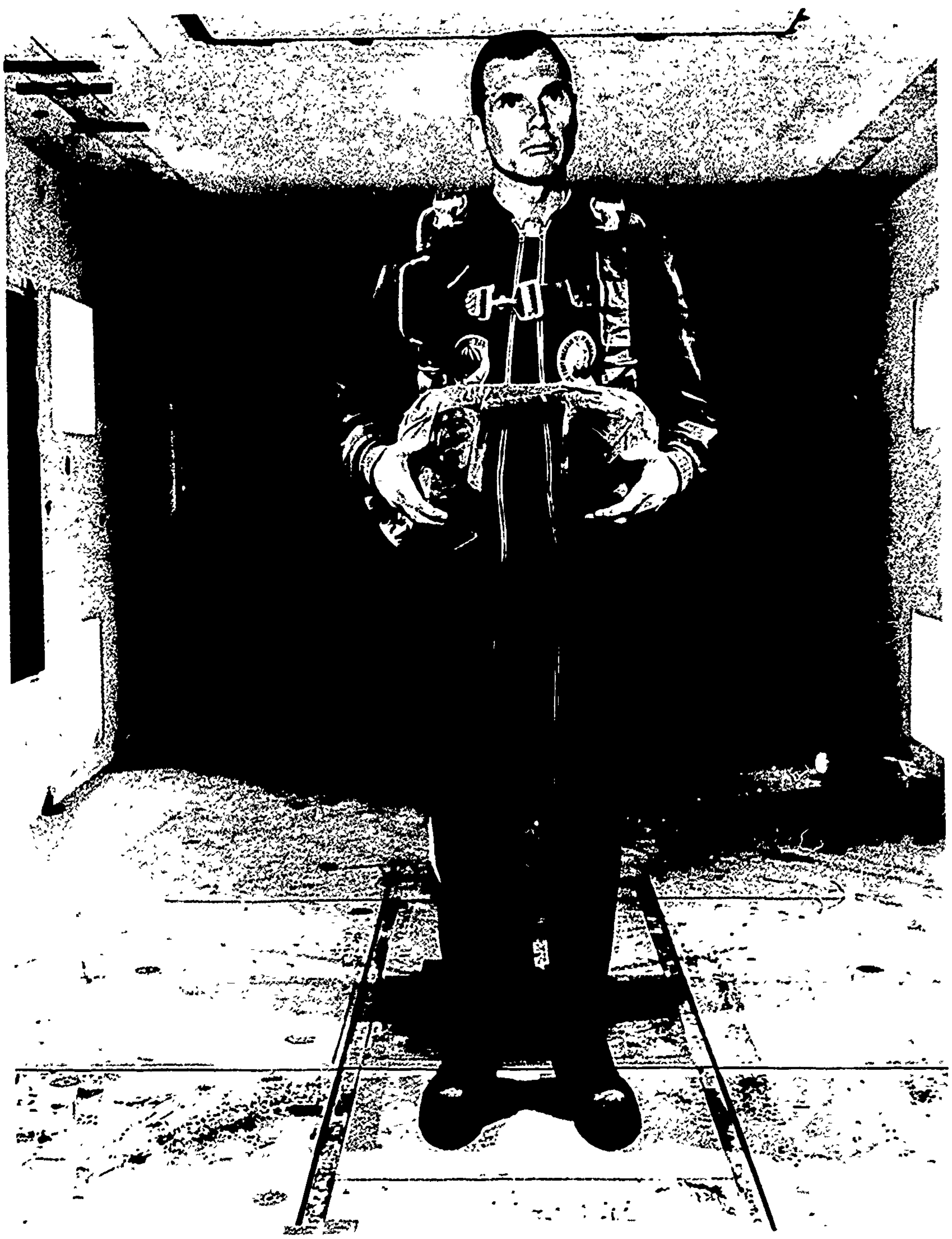


Figure 5. Parachute Pack Configuration Number 1 - Subject No. 1

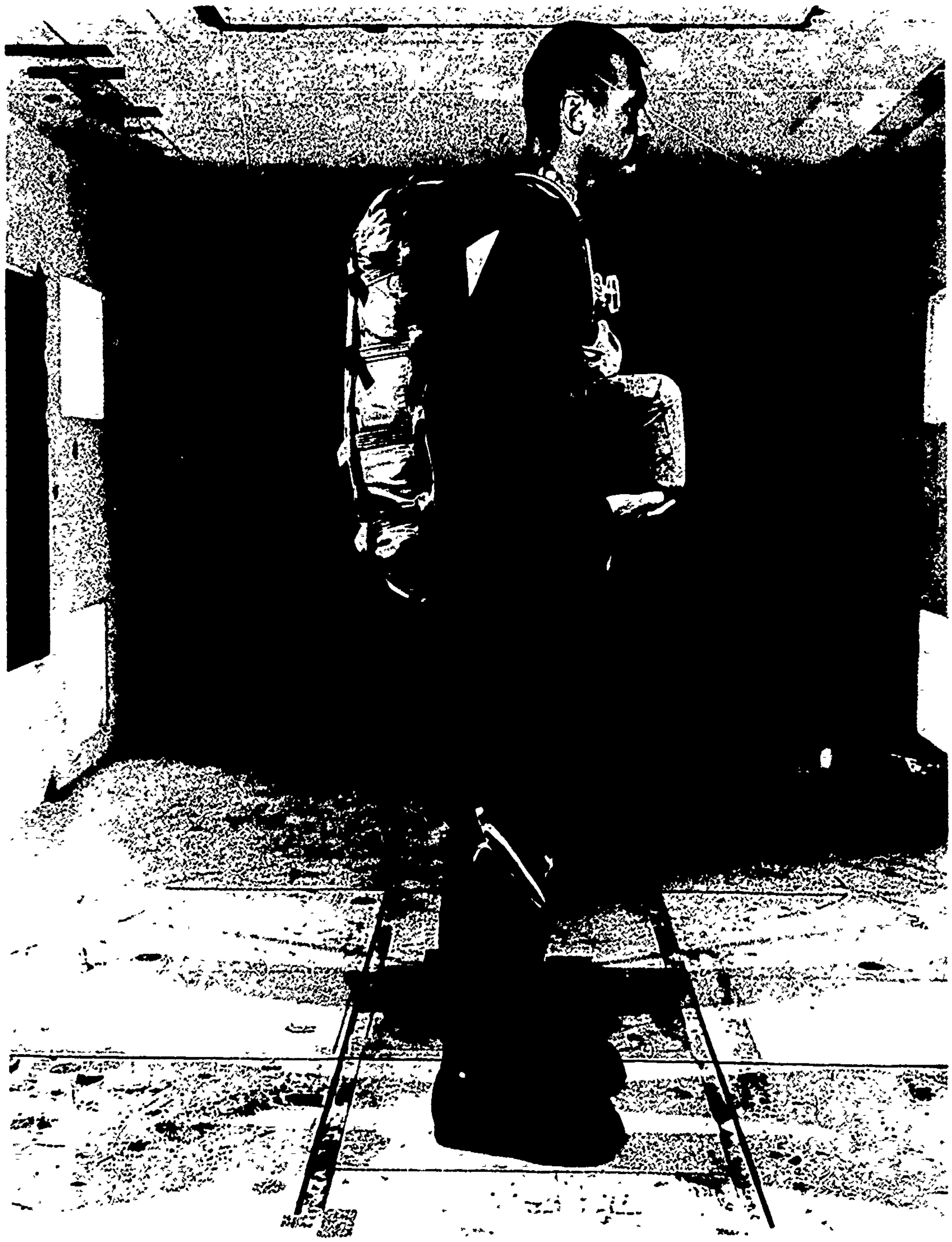


Figure 5. Concluded

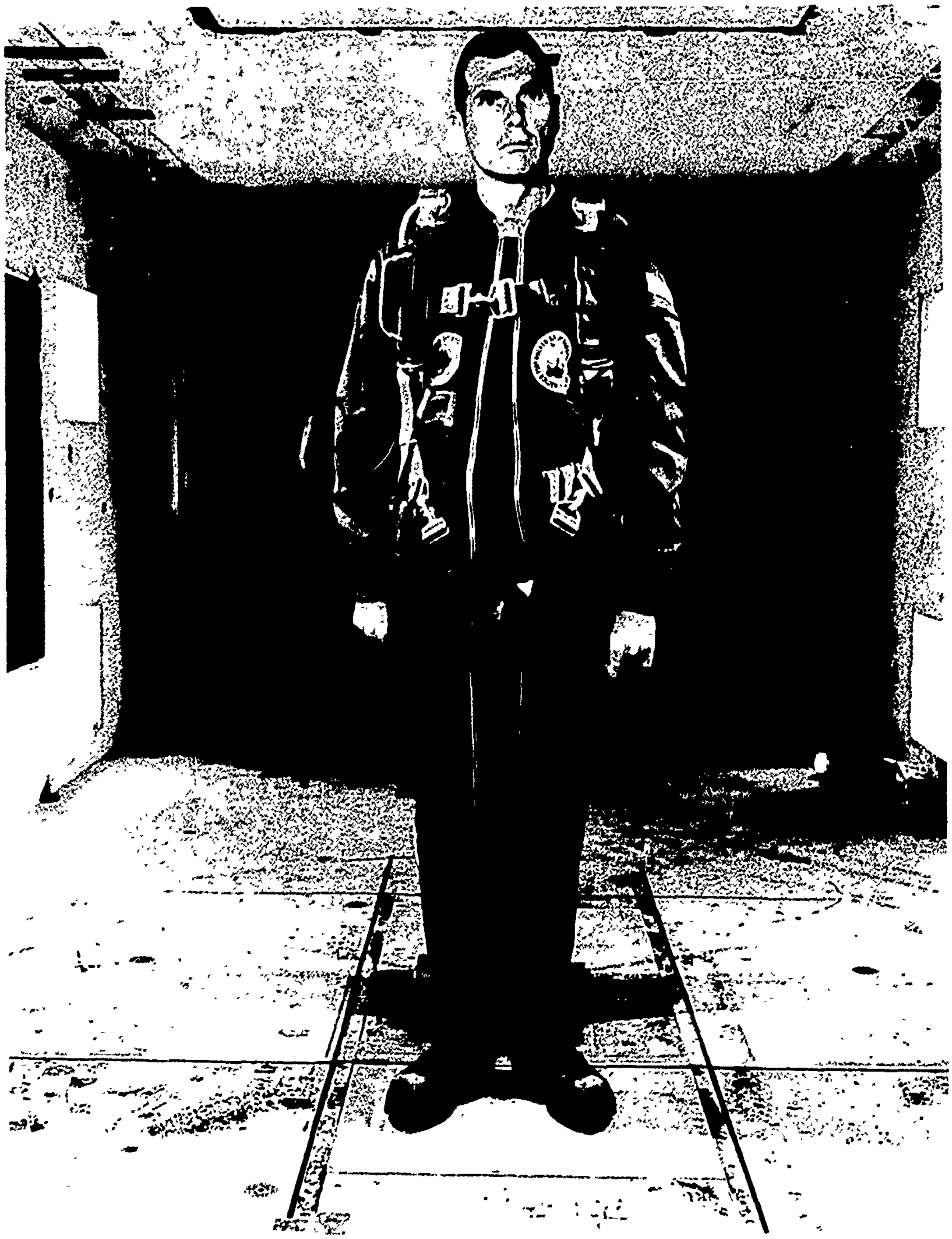


Figure 6. Parachute Pack Configuration Number 2 - Subject No. 1

Figure 6. Concluded

Figure 7. Parachute Pack Configuration Number 3 - Subject No. 3

Figure 7. Concluded

Figure 8. Parachute Pack Configuration Number 4 - Subject No. 2

Figure 8. Concluded

Figure 9. Parachute Pack Configuration Number 5 - Subject No. 4

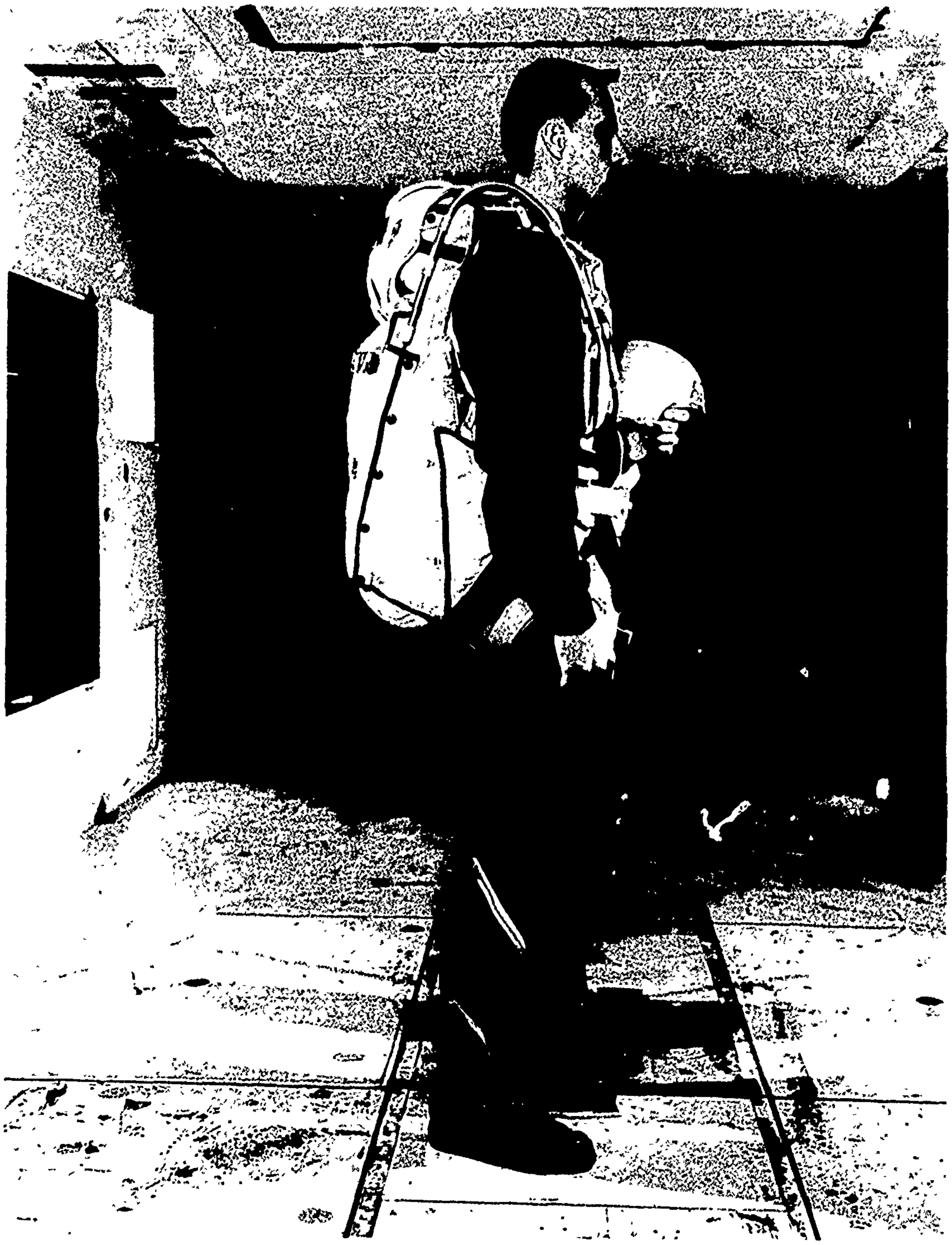


Figure 9. Concluded

Figure 10. Parachute Pack Configuration Number 6 - Subject No. 2

Figure 10. Concluded

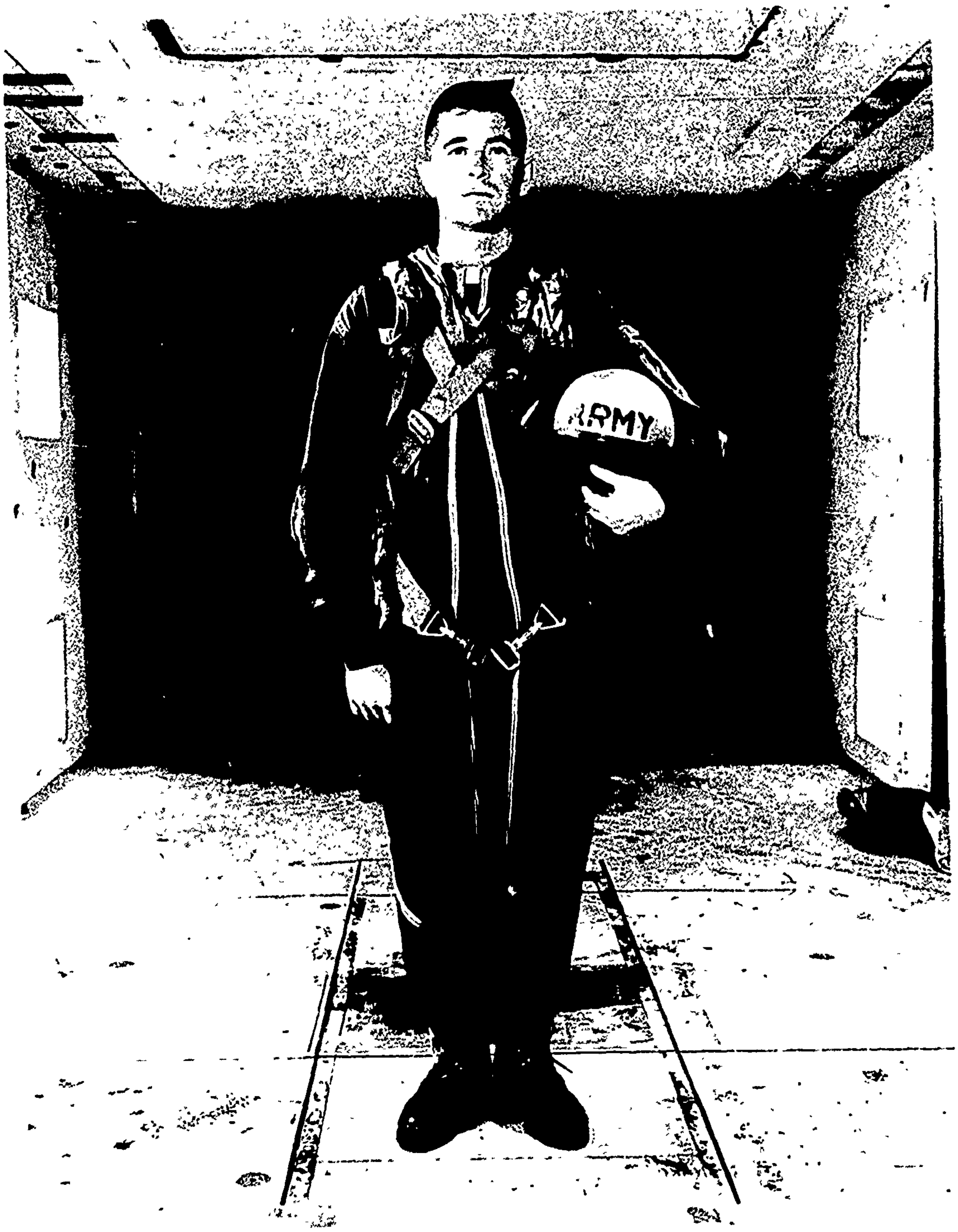


Figure 11. Parachute Pack Configuration Number 7 - Subject No. 5

Figure 11. Concluded

Figure 12. Parachute Pack Configuration Number 8 - Subject No. 1

Figure 12. Concluded

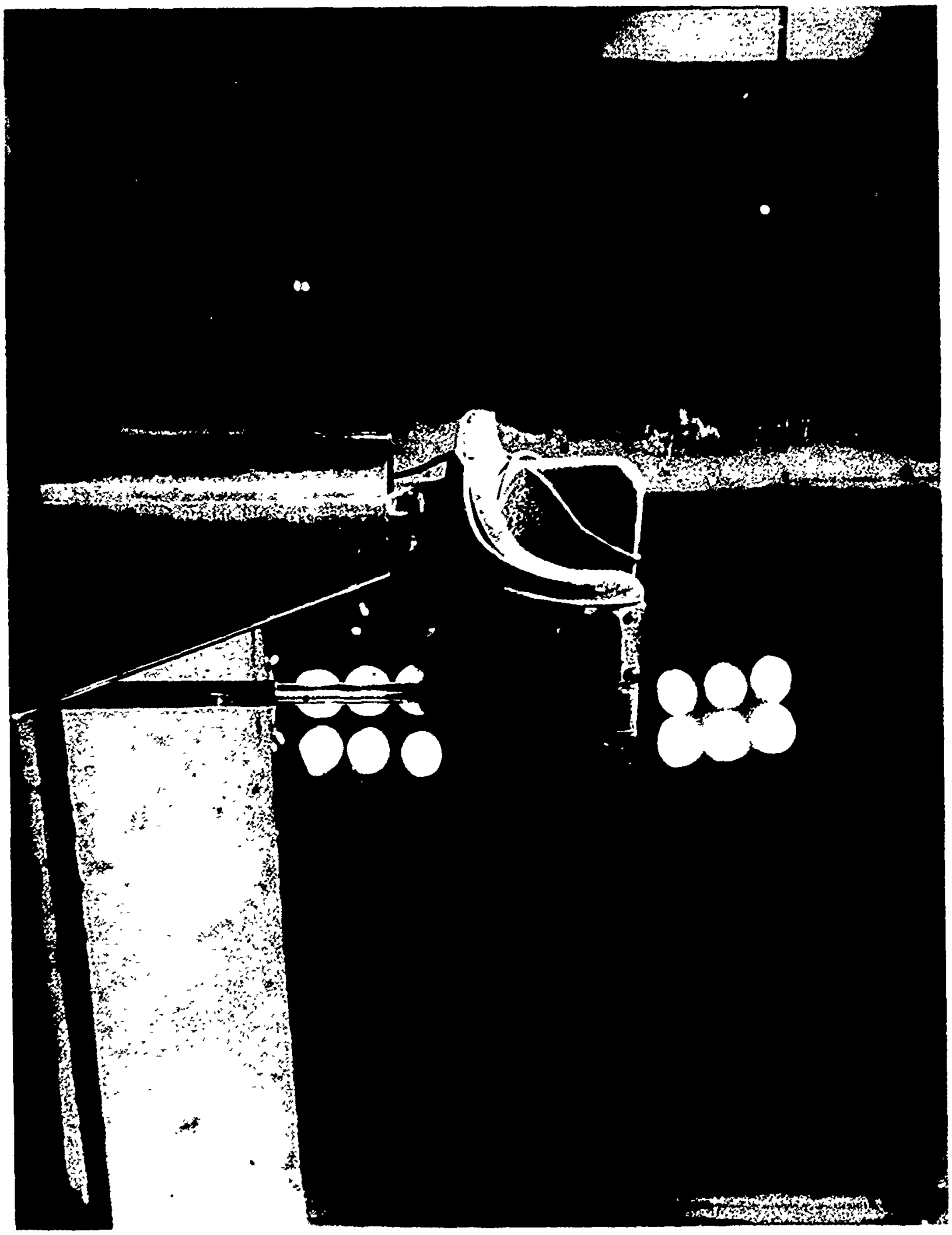


Figure 13. Cradle and Strut Assembly

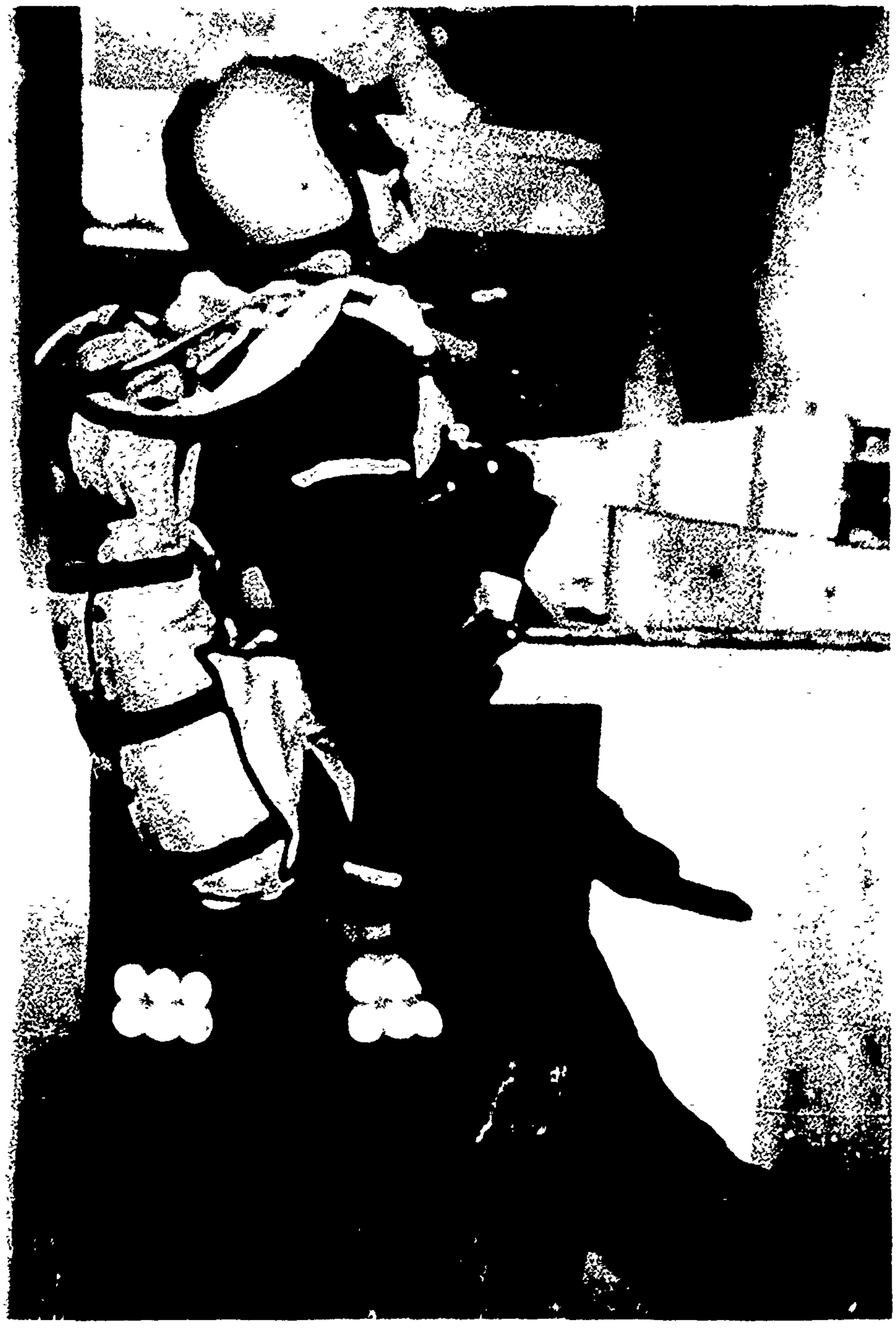
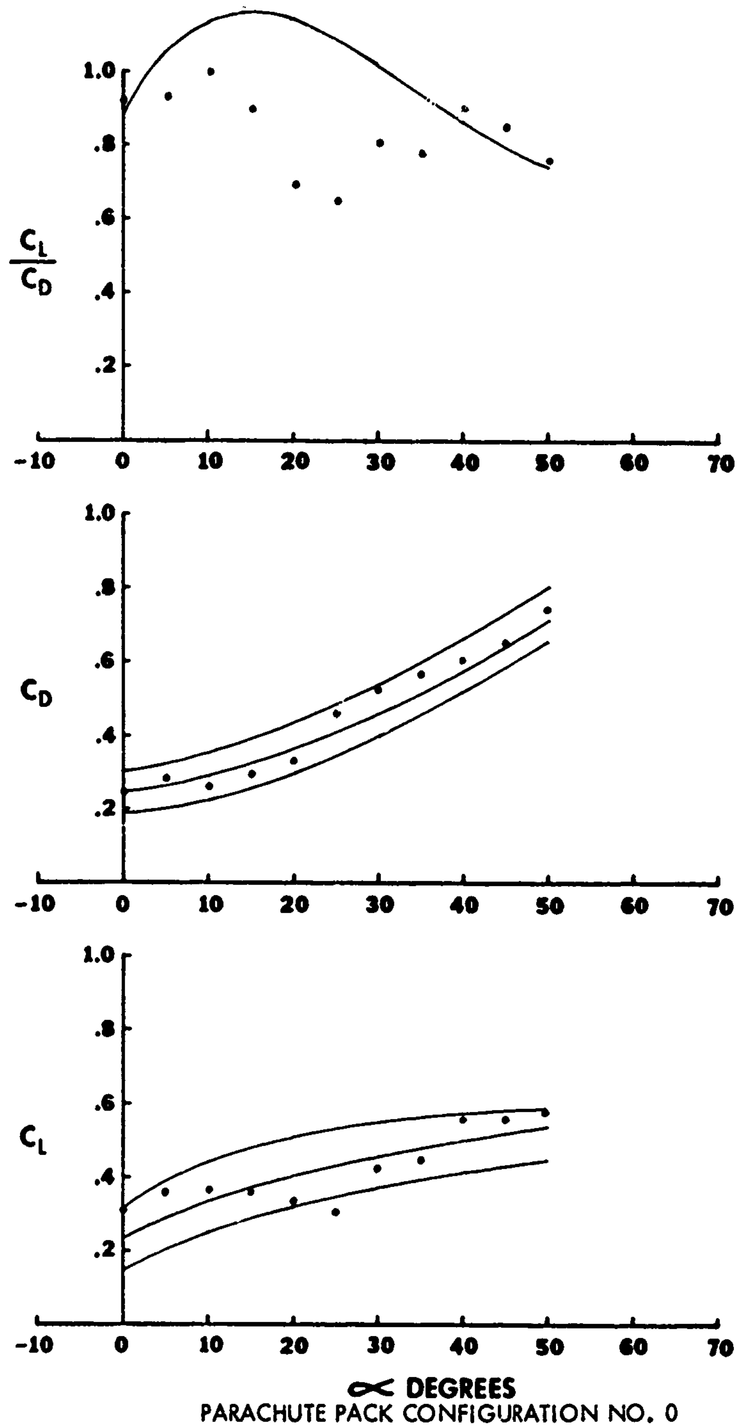
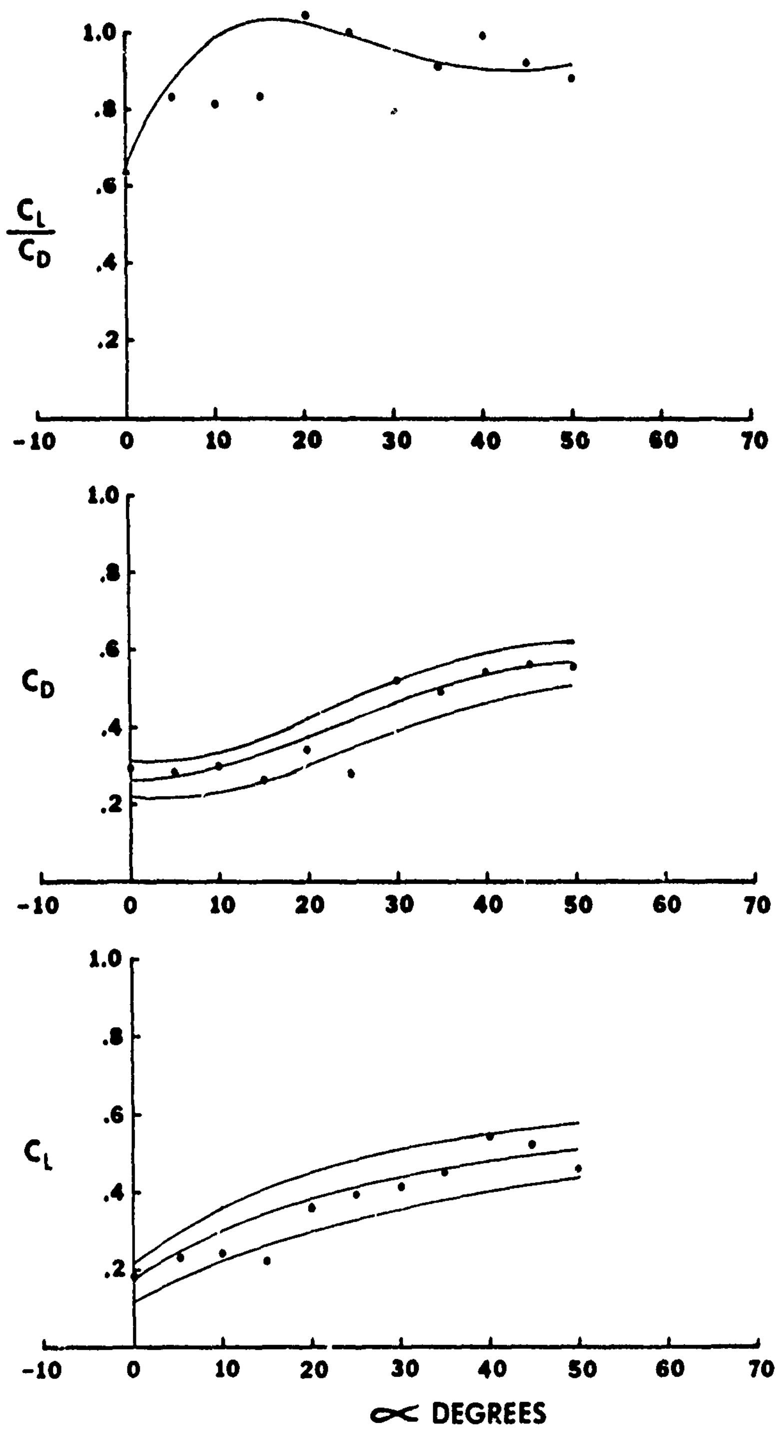


Figure 14. Subject Mounted in Wind Tunnel



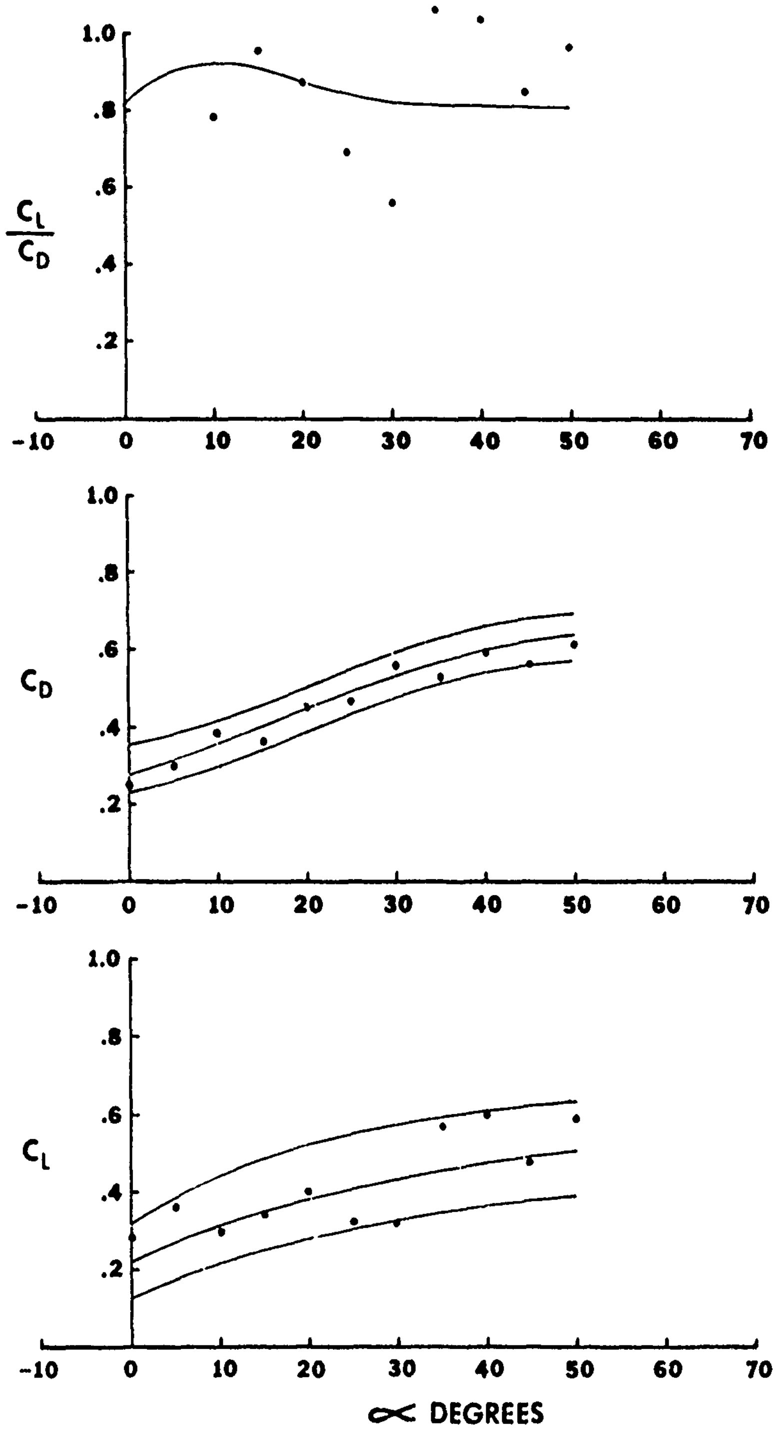
PARACHUTE PACK CONFIGURATION NO. 0
SUBJECT NO. 1

Figure 15 (a)



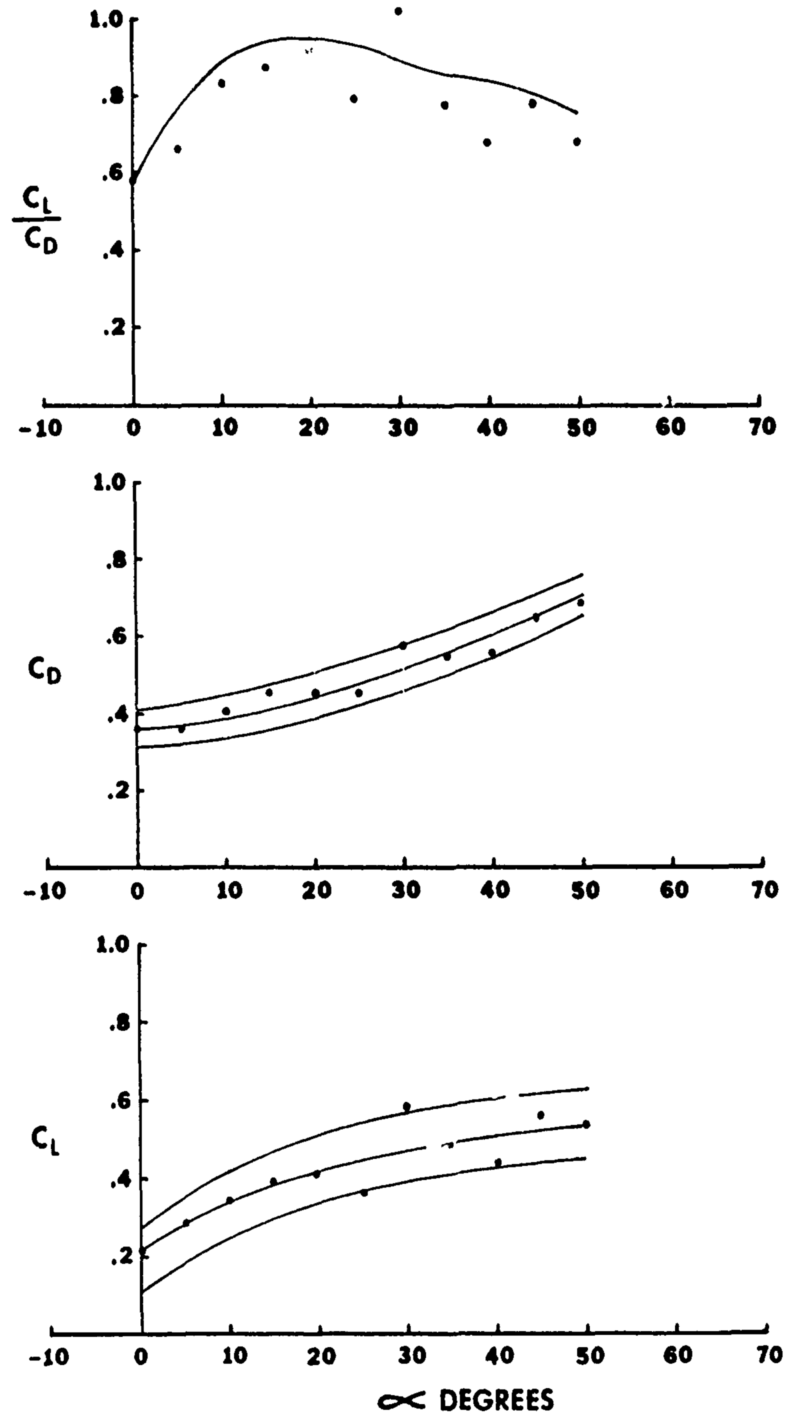
SUBJECT NO. 2

Figure 15 (b)



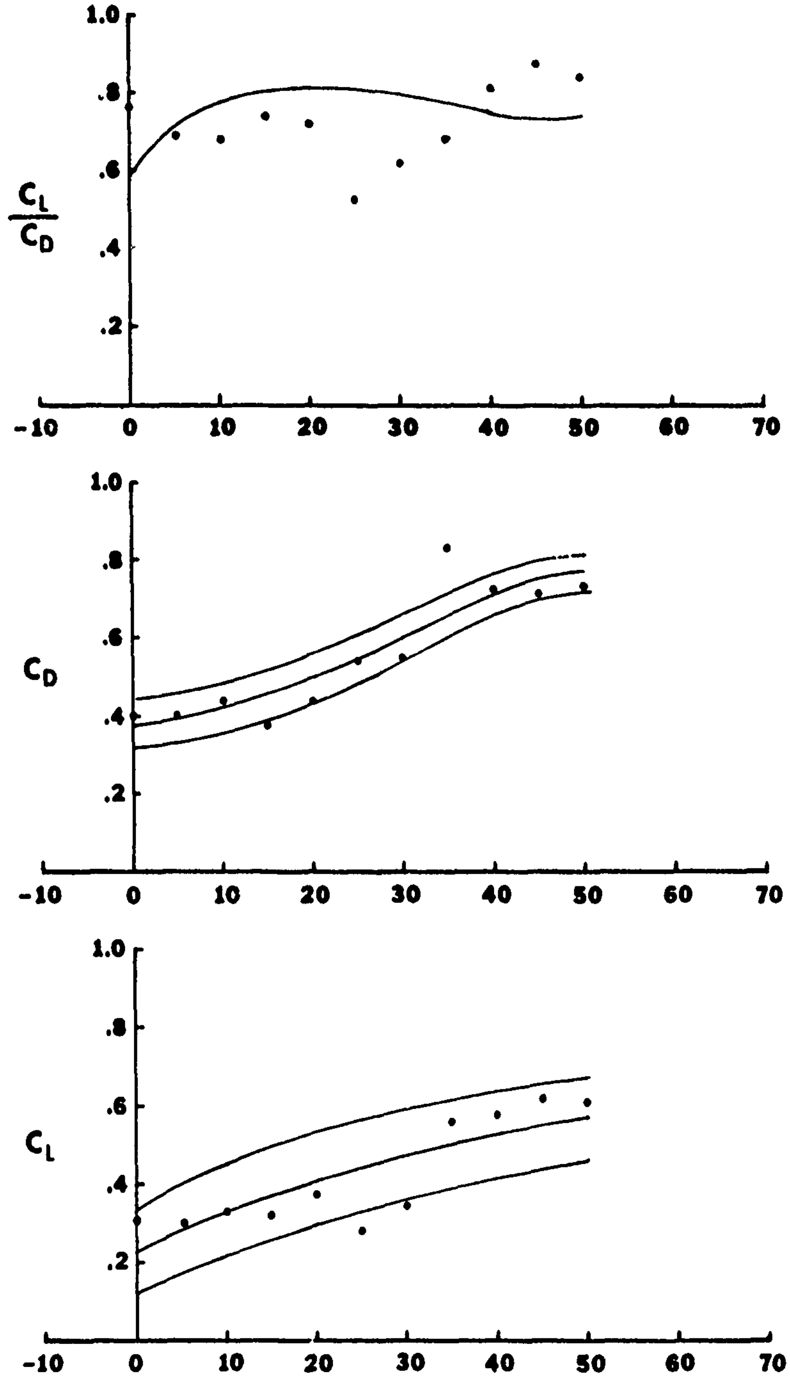
SUBJECT NO. 3

Figure 15 (c)



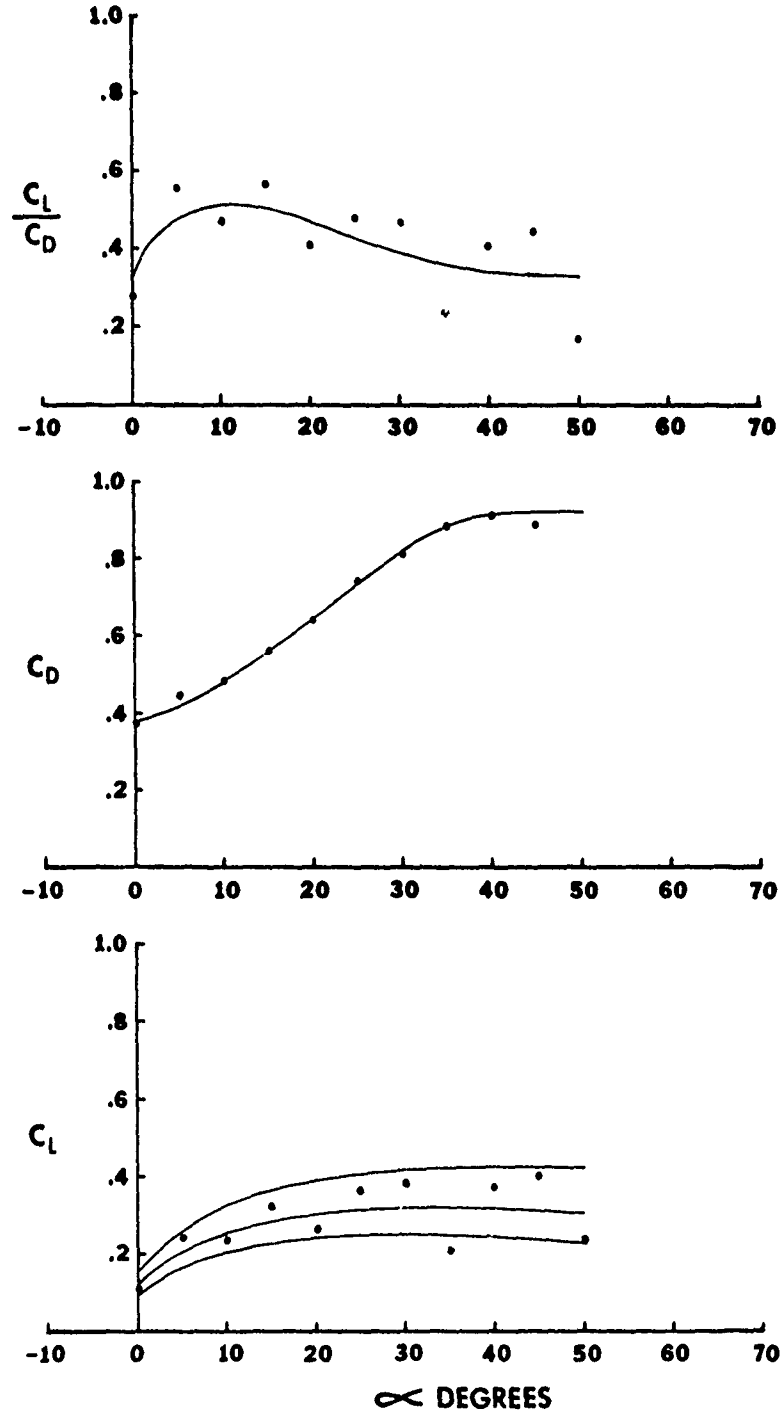
SUBJECT NO. 4

Figure 15 (d)



SUBJECT NO. 5

Figure 15 (e)



PARACHUTE PACK CONFIGURATION NO. 1
SUBJECT NO. 1

Figure 16 (a)

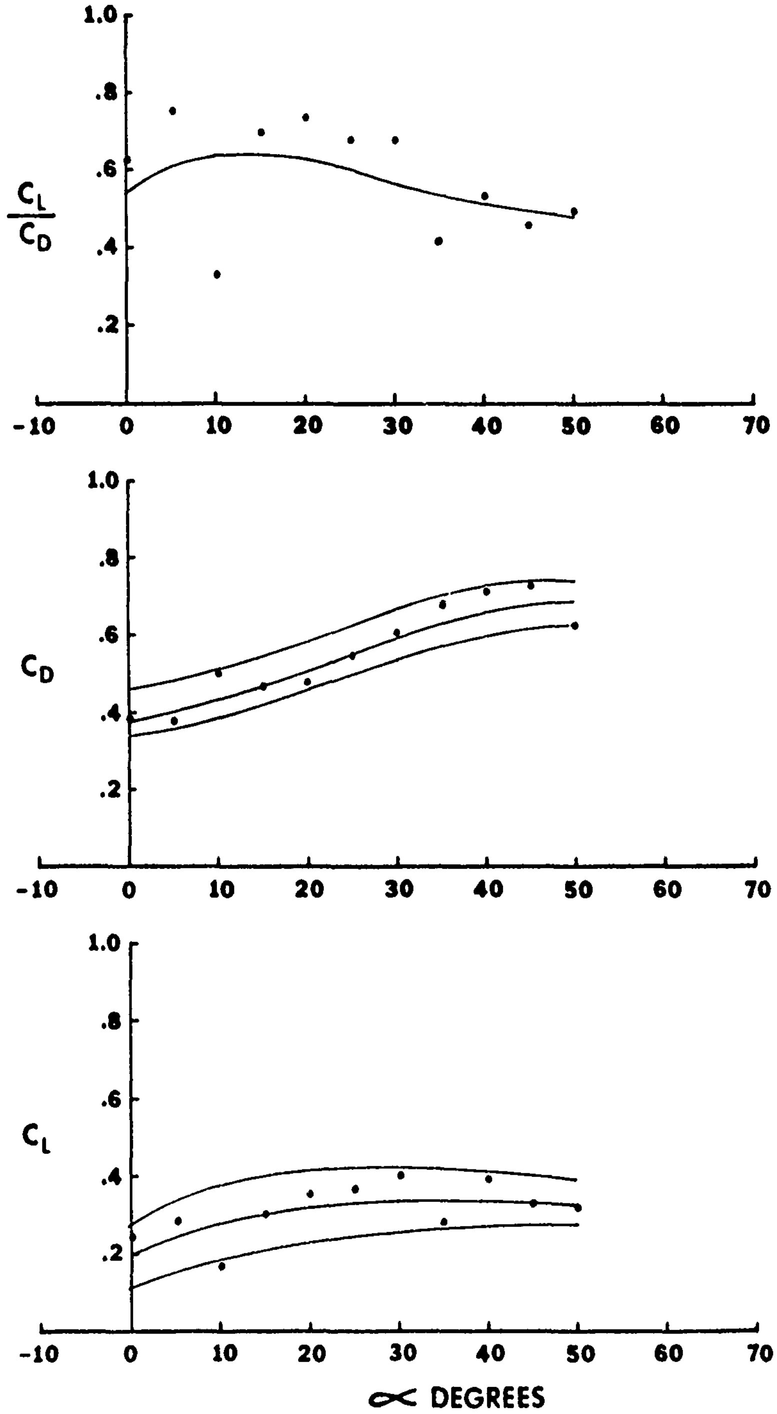
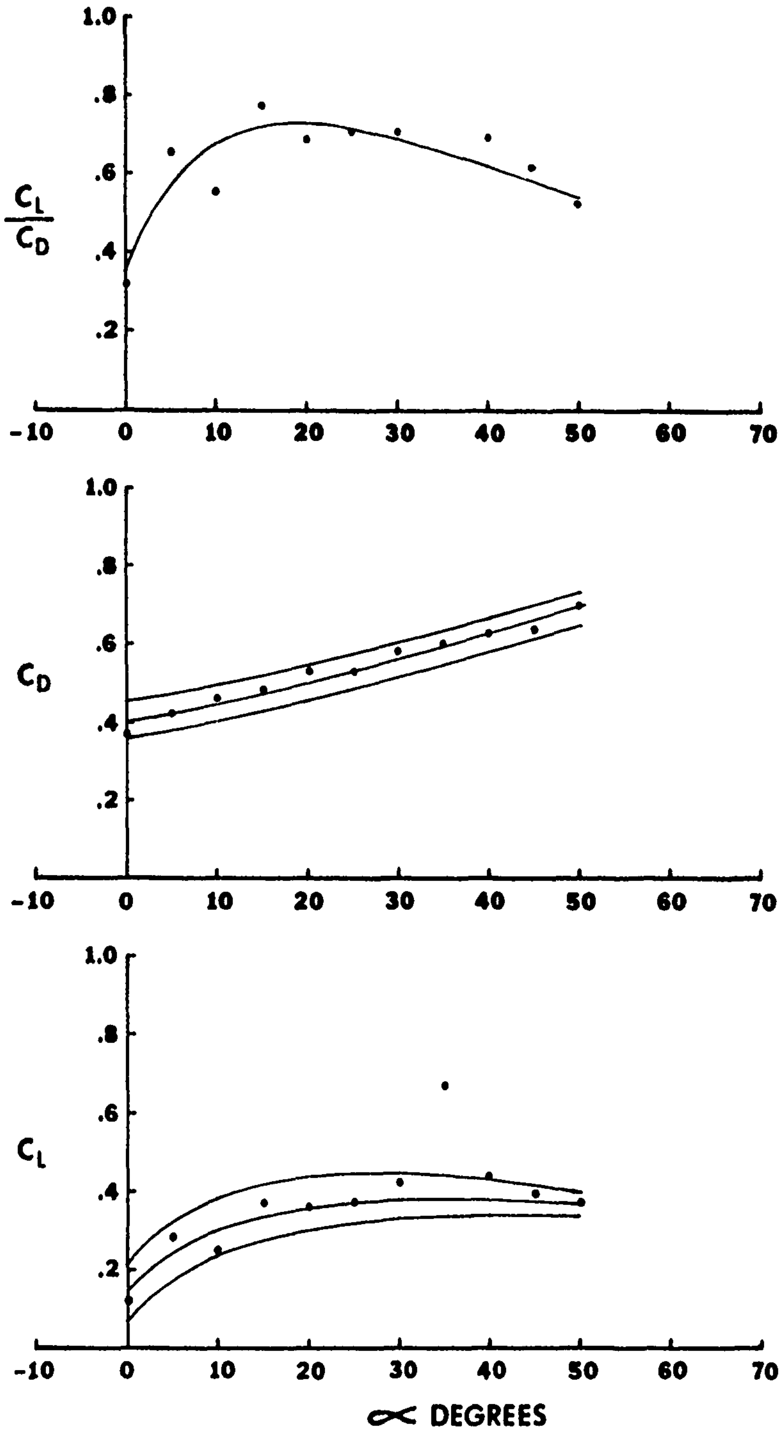
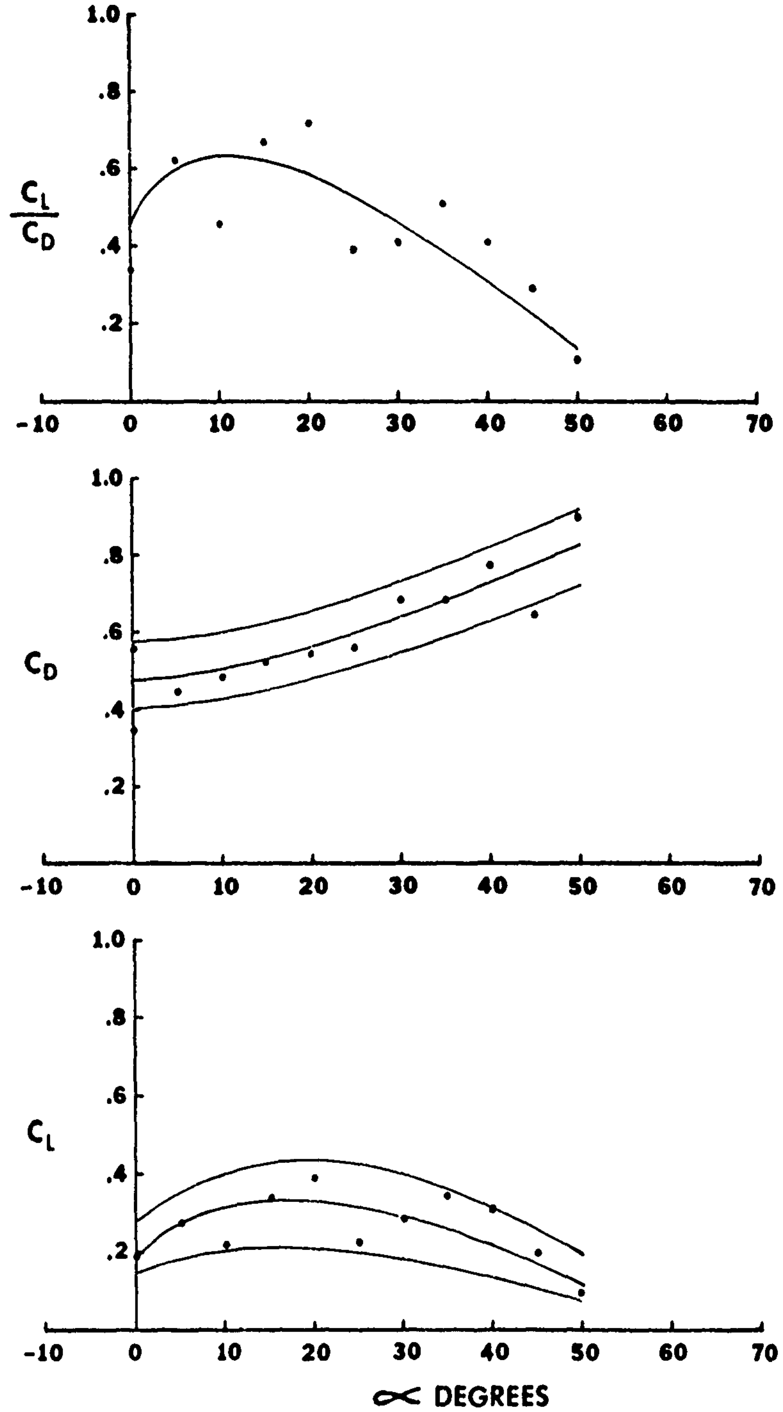

1.0
.8
.6
.4
.2
$\frac{C_L}{C_D}$
-10
0
10
20
30
40
50
60
70
C_D
C_L
∝ DEGREES
SUBJECT NO. 2

Figure 16 (b)



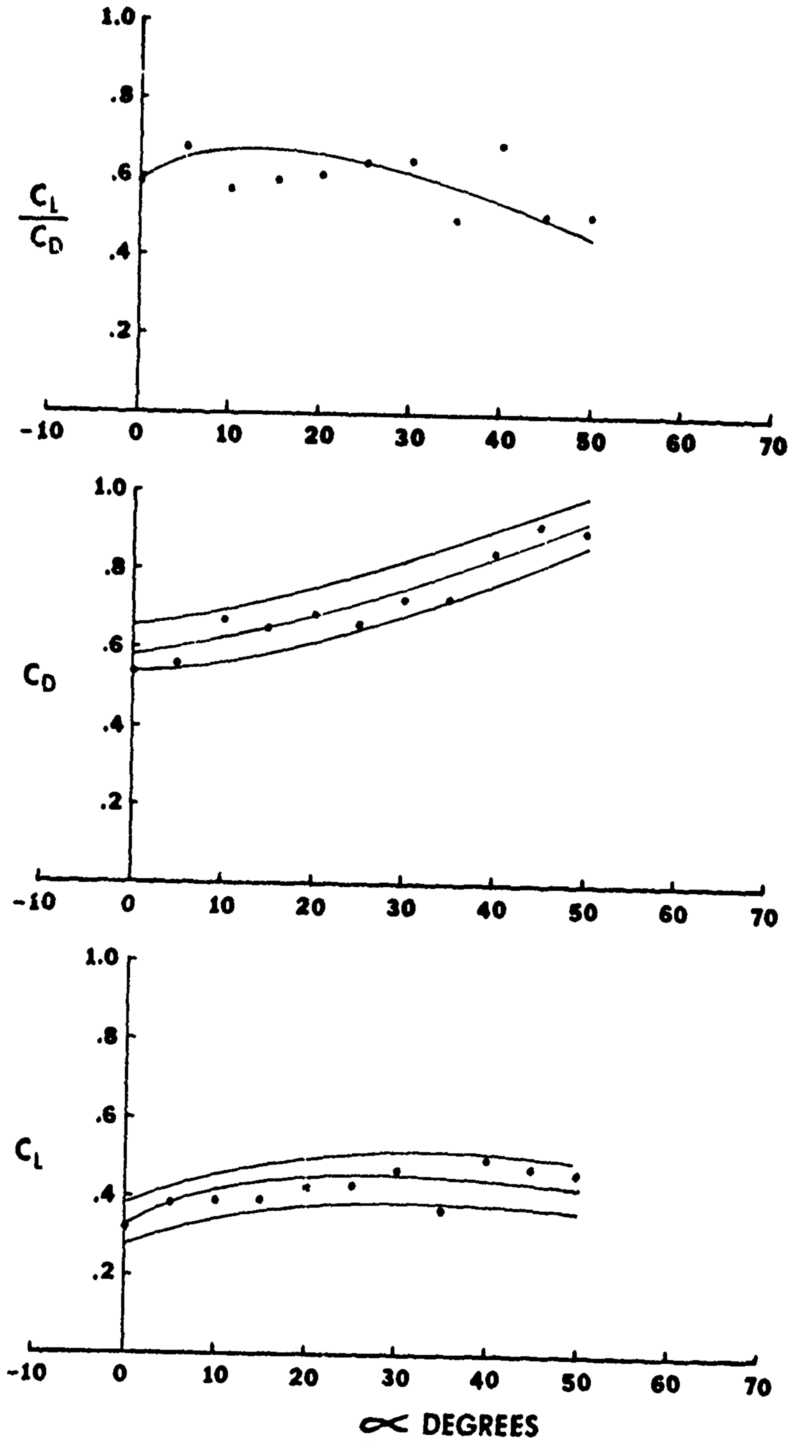
SUBJECT NO. 3

Figure 16 (c)



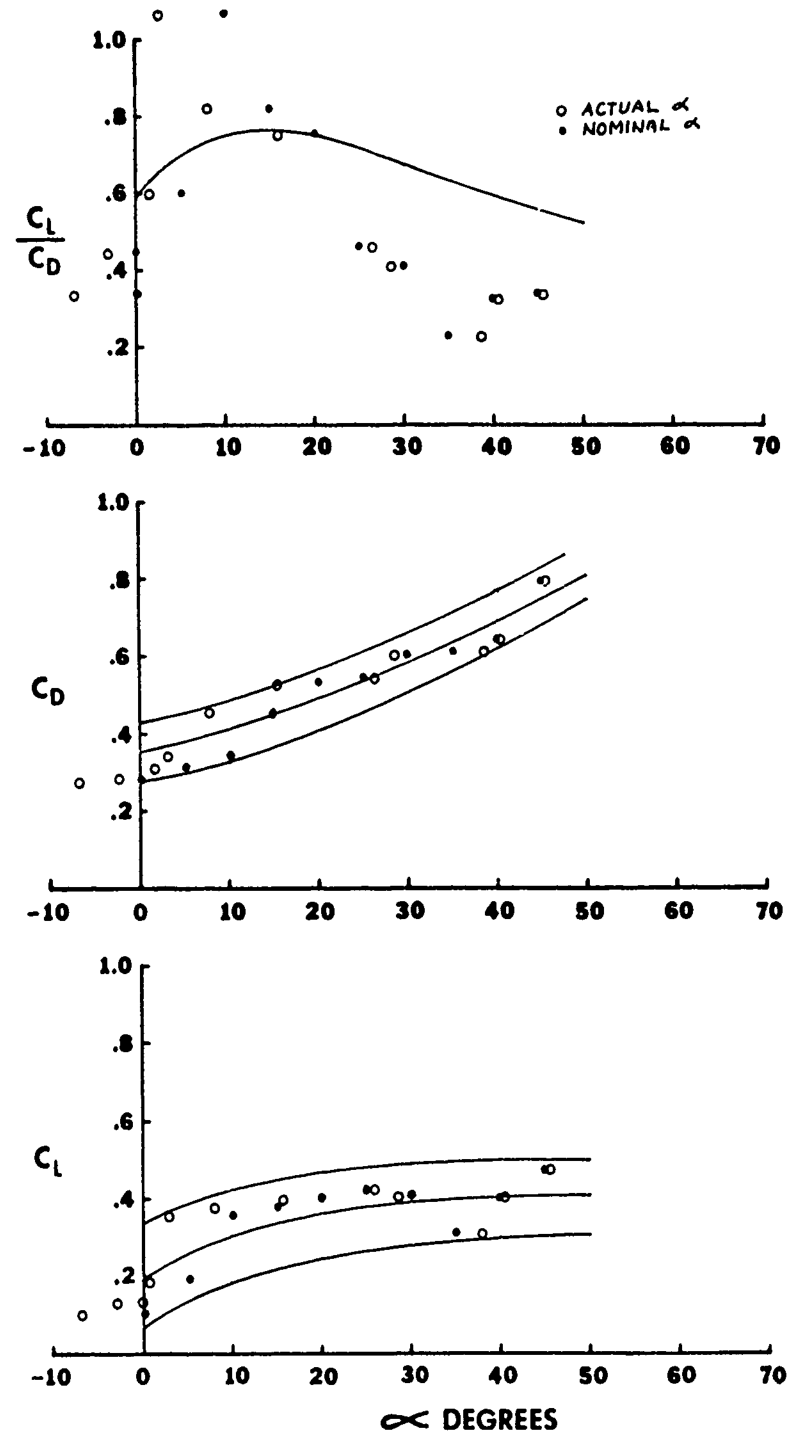
SUBJECT NO. 4

Figure 16 (d)



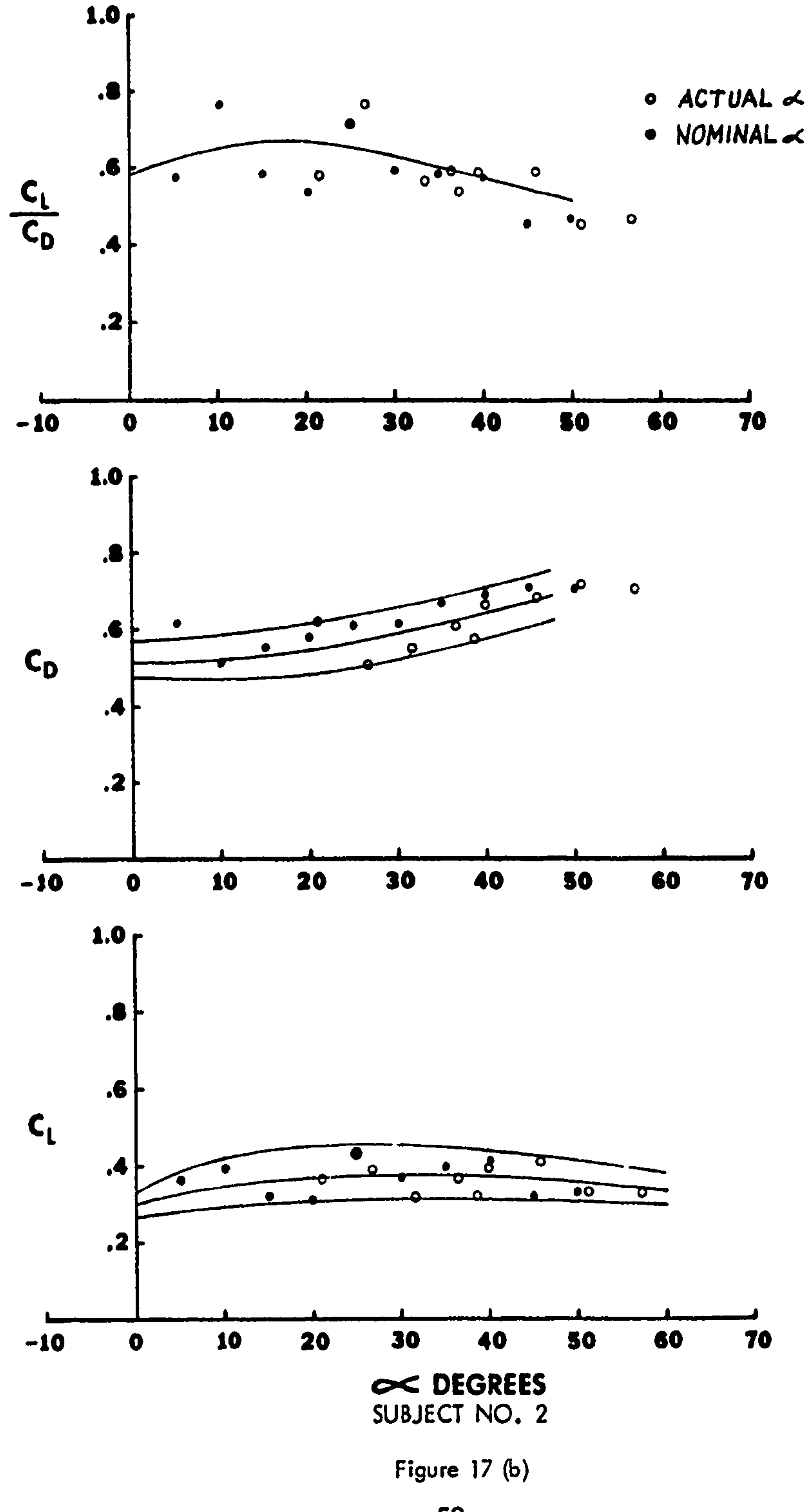
SUBJECT NO. 5

Figure 16 (e)



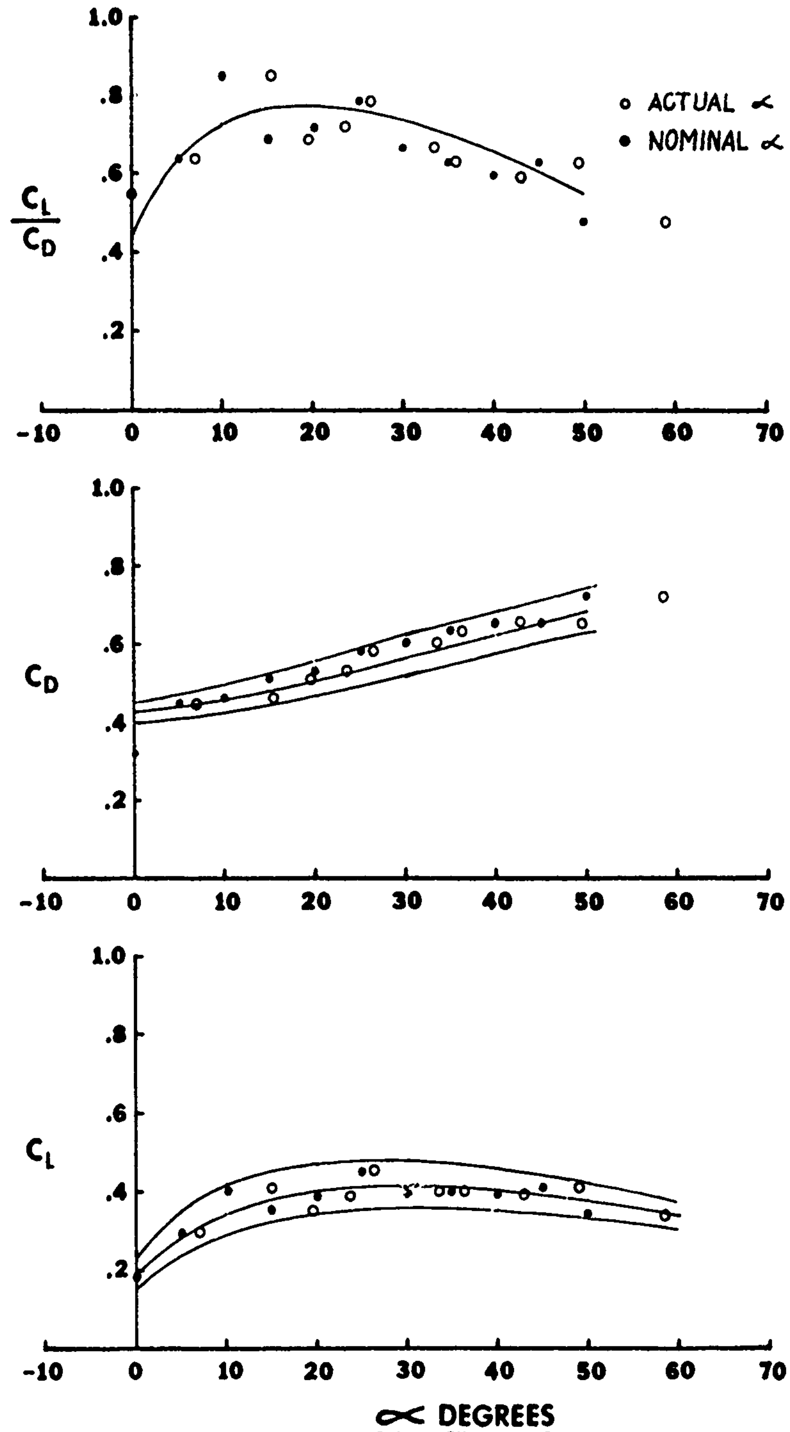
PARACHUTE PACK CONFIGURATION NO. 2
SUBJECT NO. 1

Figure 17 (a)



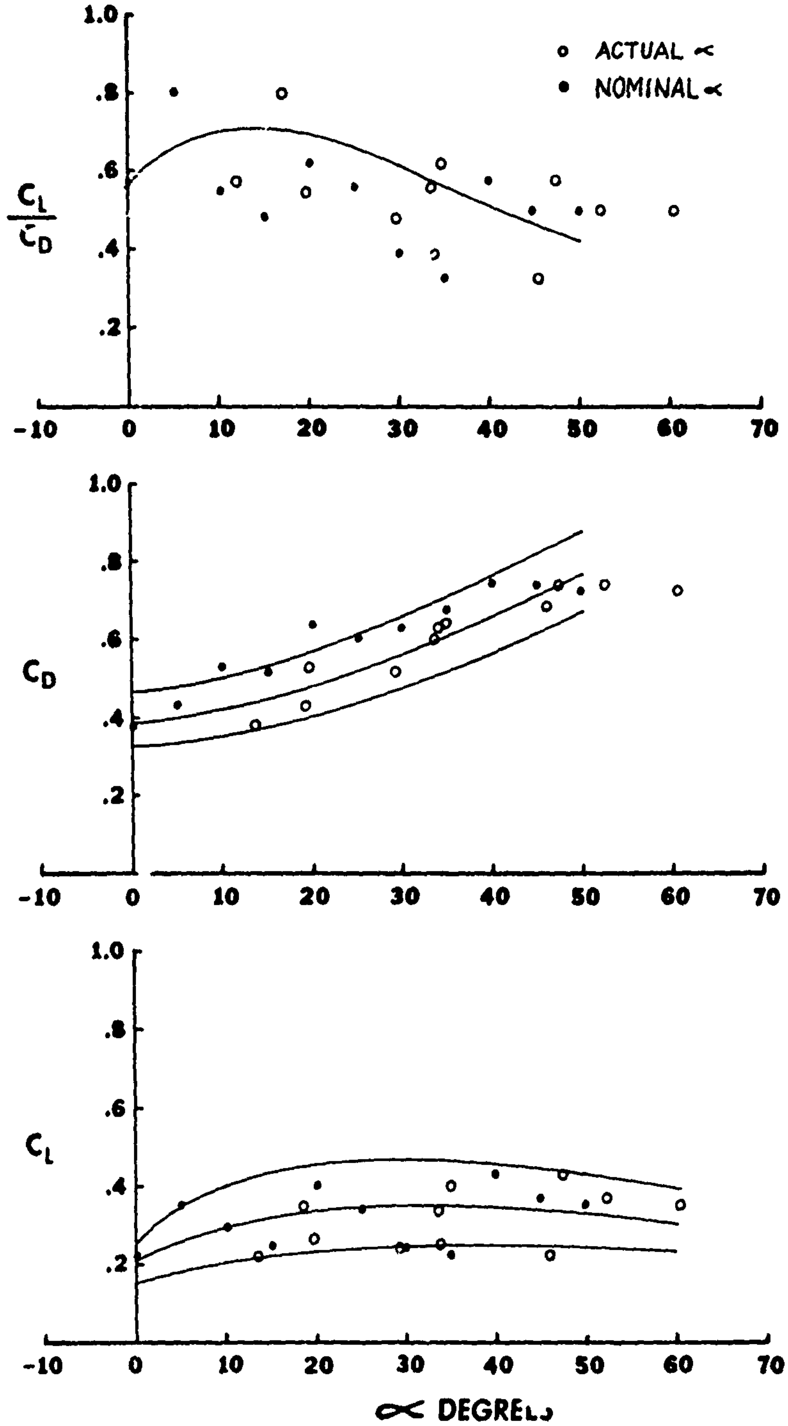
SUBJECT NO. 2

Figure 17 (b)



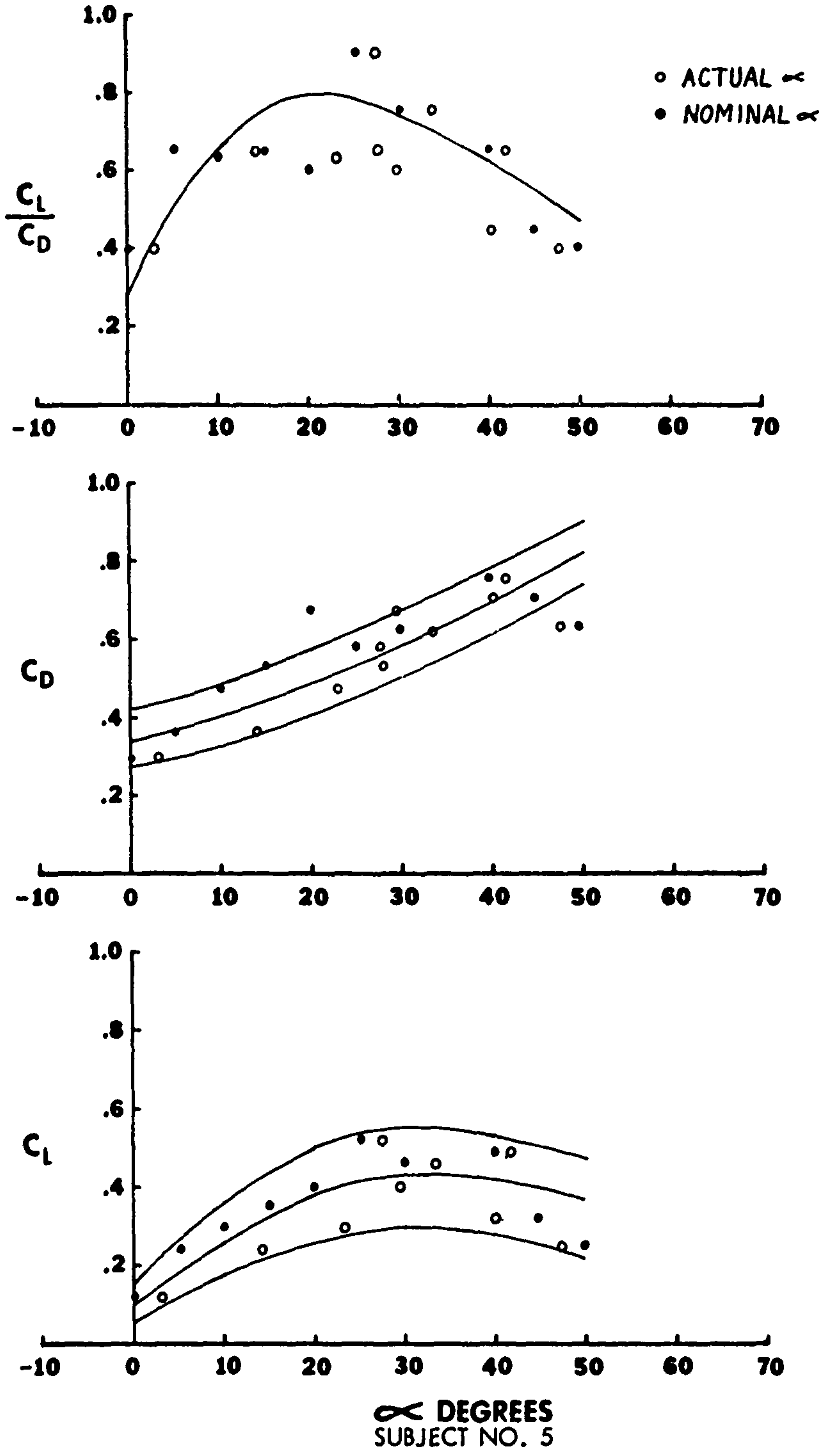
SUBJECT NO. 3

Figure 17 (c)



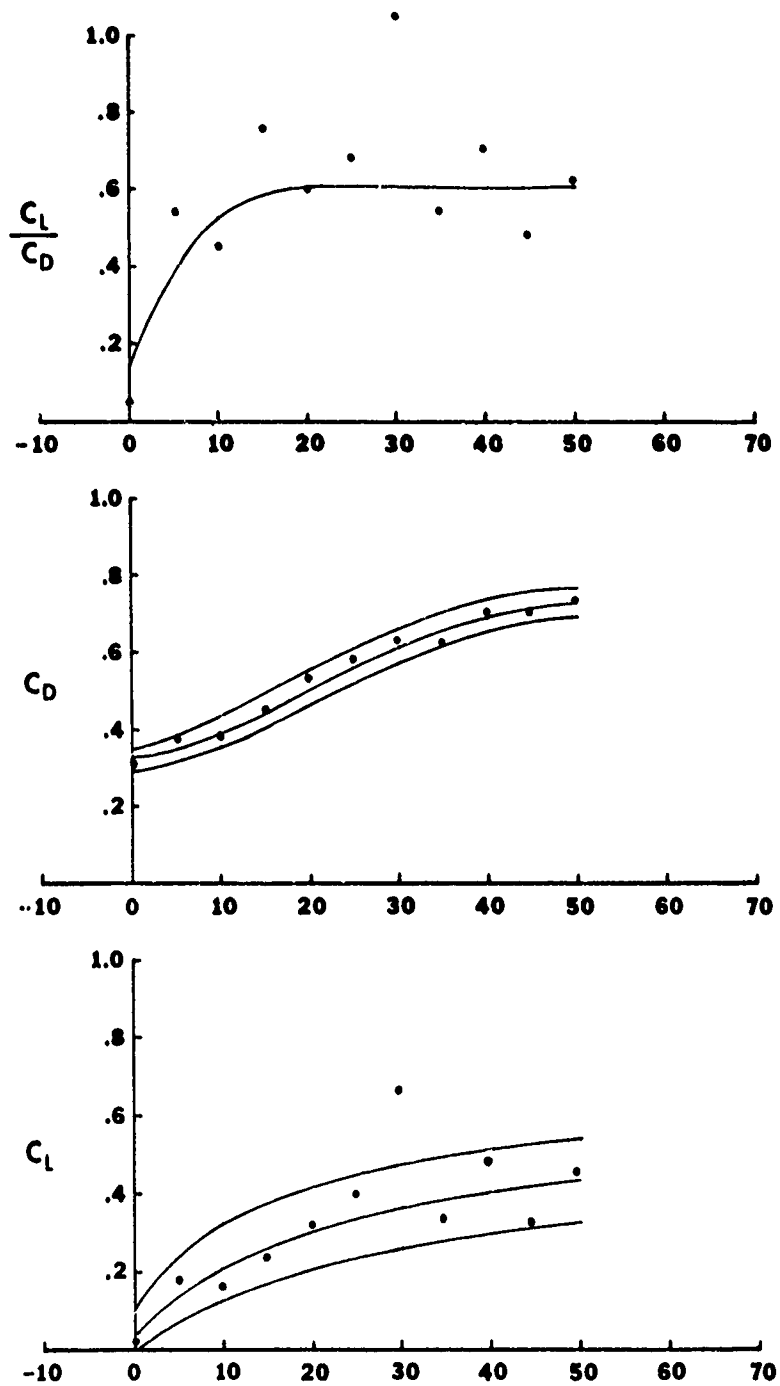
SUBJECT NO. 4

Figure 17 (d)



SUBJECT NO. 5

Figure 17 (e)

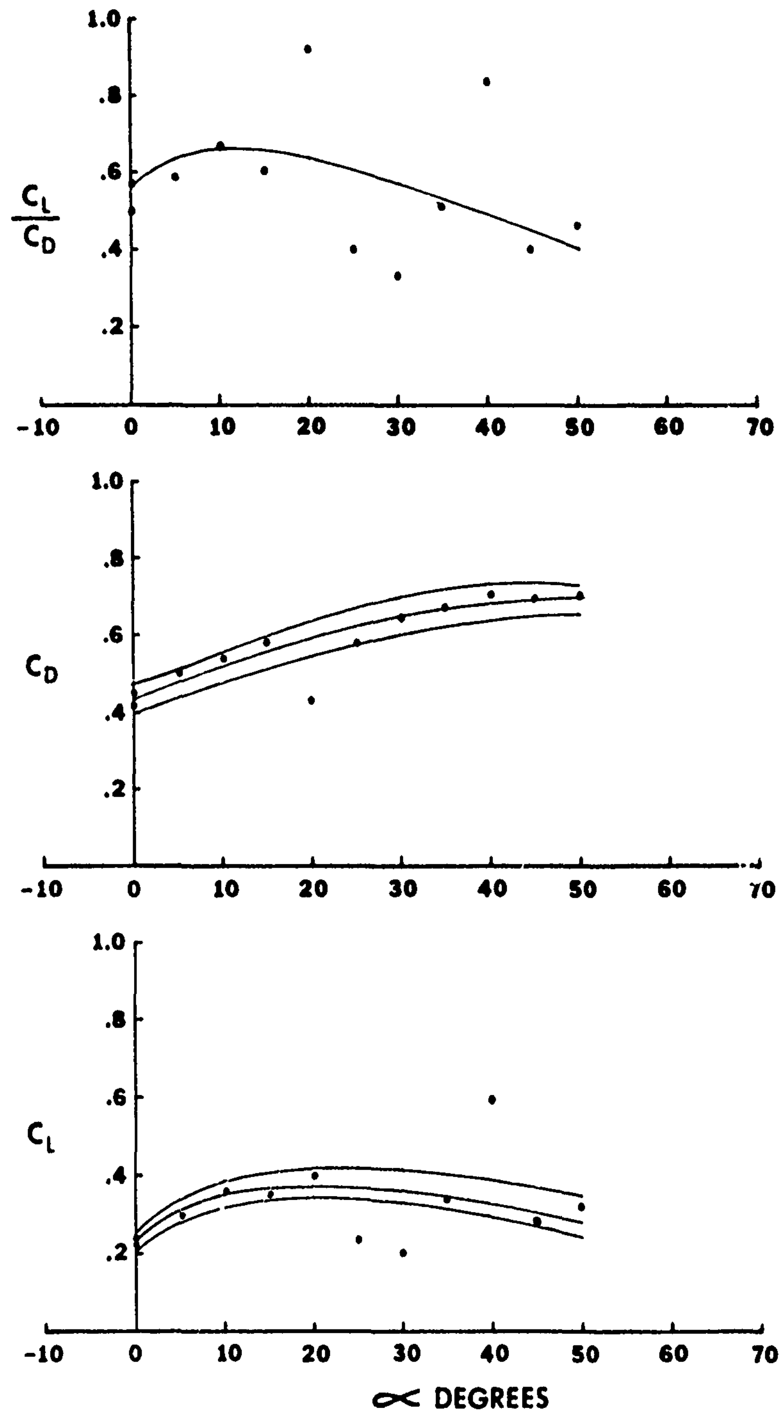


α DEGREES

PARACHUTE PACK CONFIGURATION NO. 3

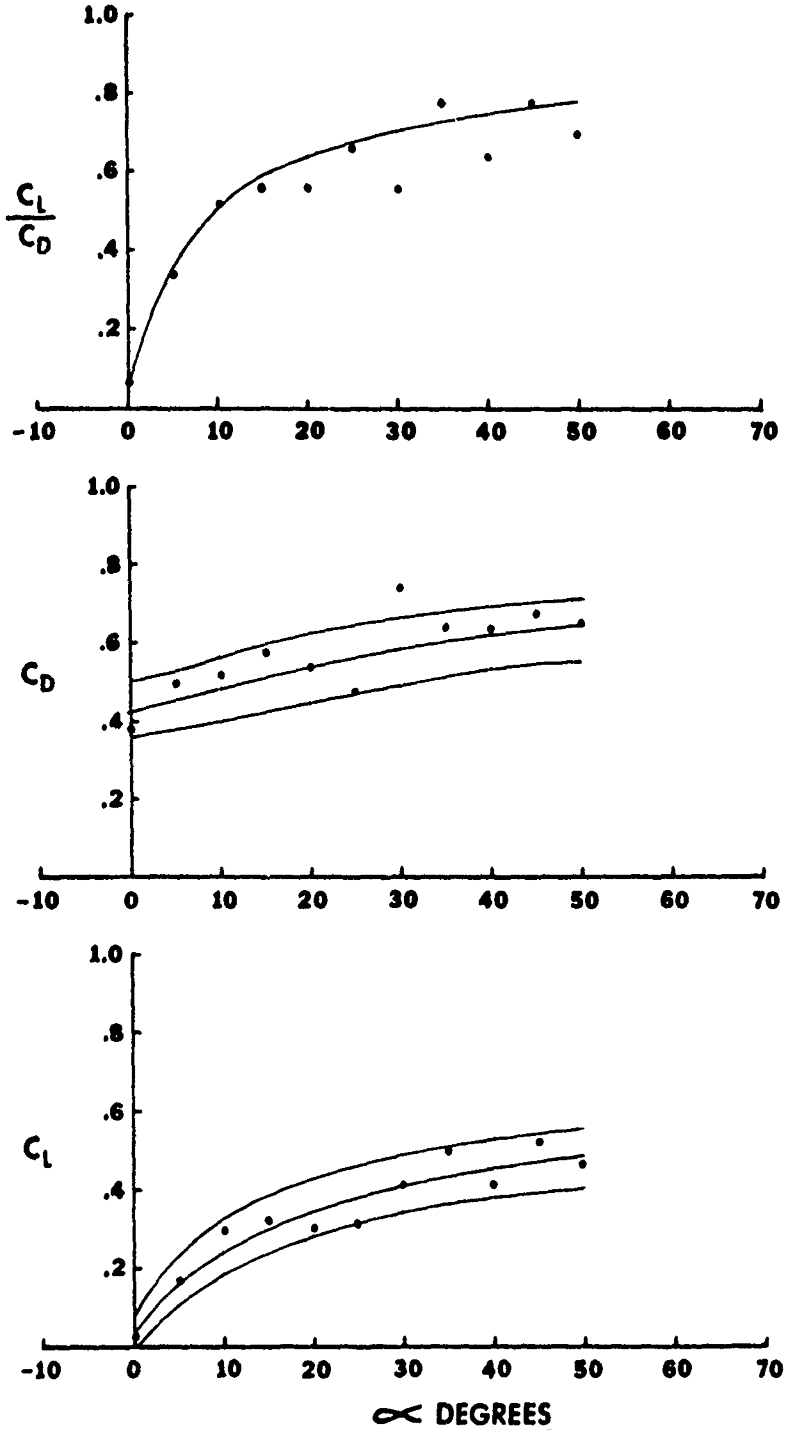
SUBJECT NO. 1

Figure 18 (a)



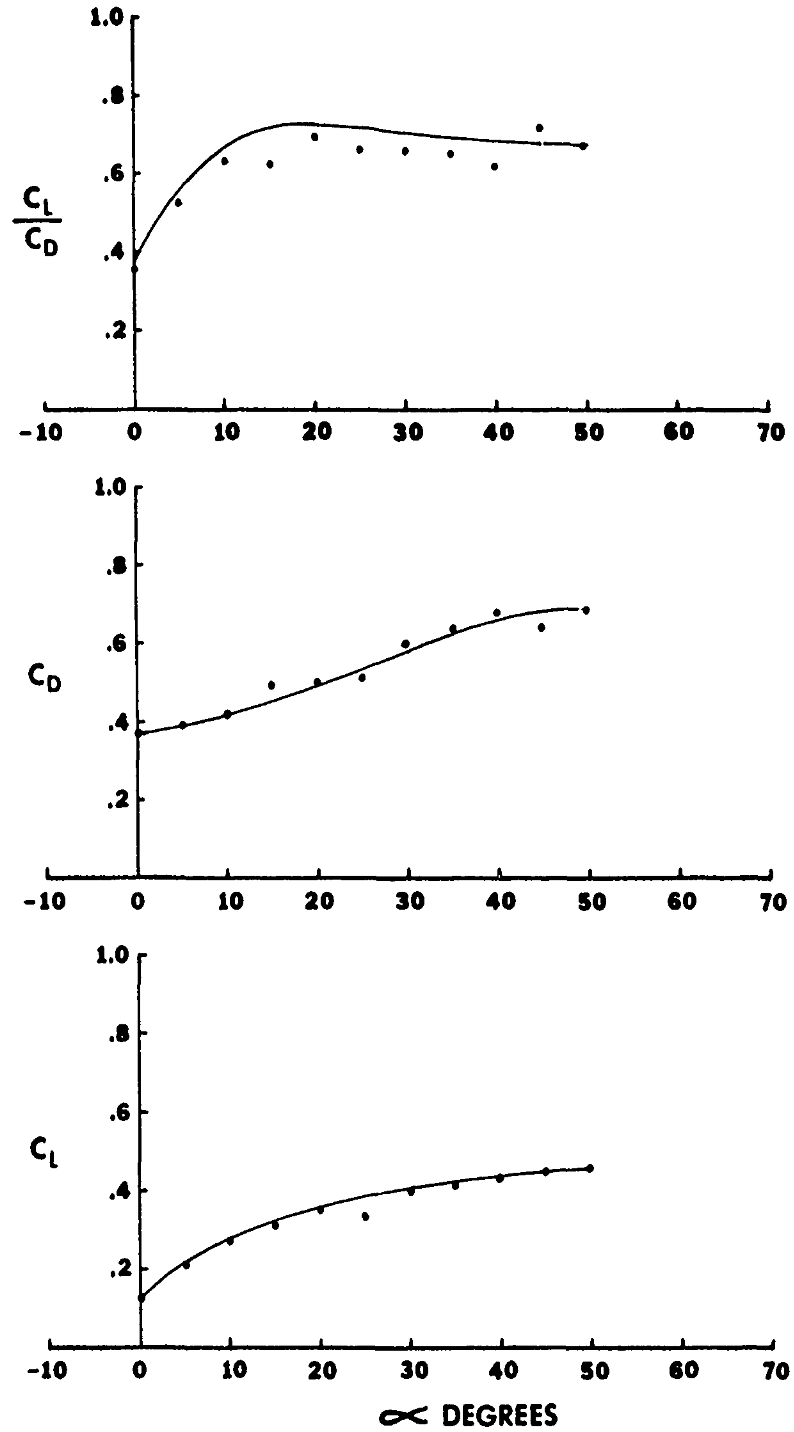
SUBJECT NO. 2

Figure 18 (b)



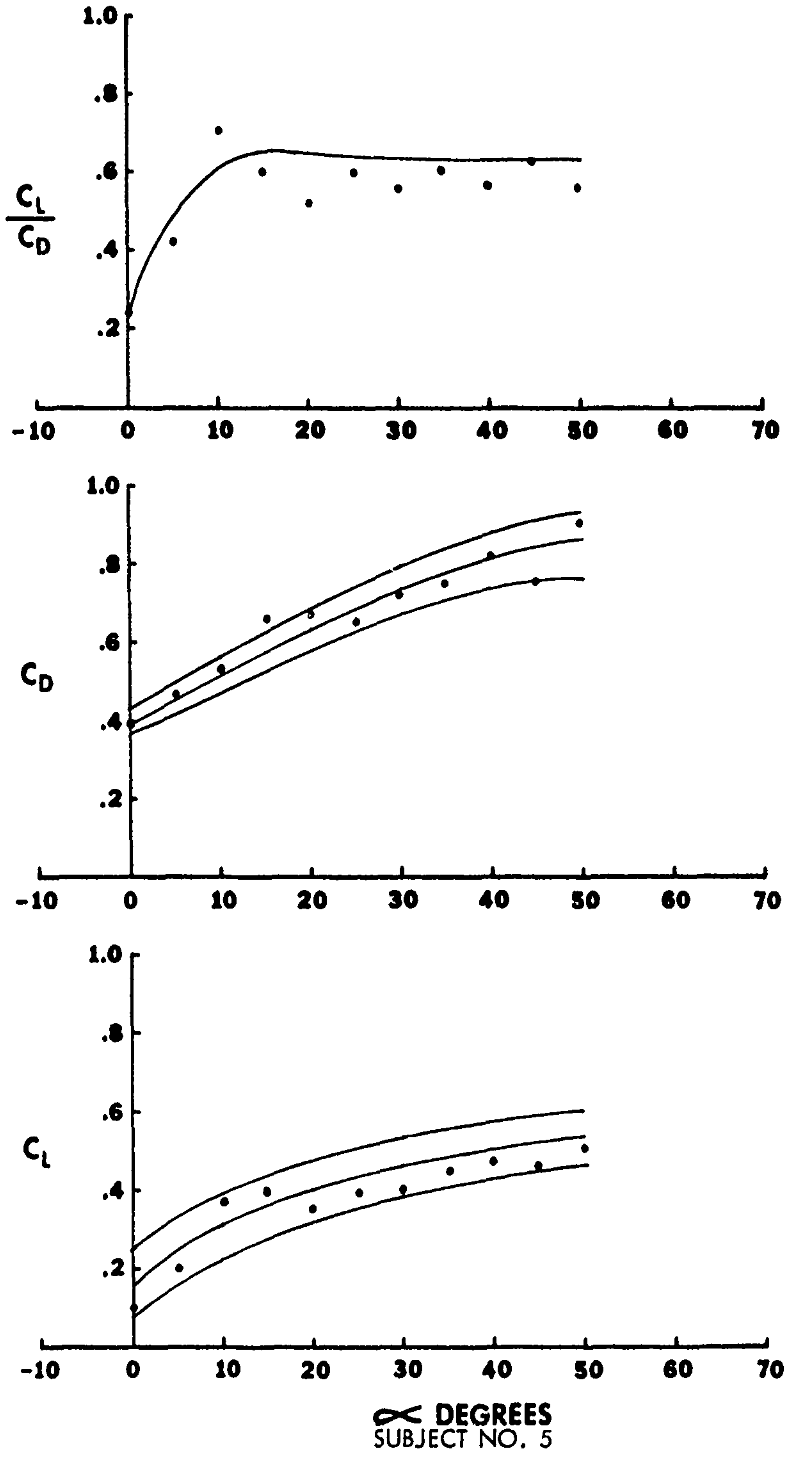
SUBJECT NO. 3

Figure 18 (c)



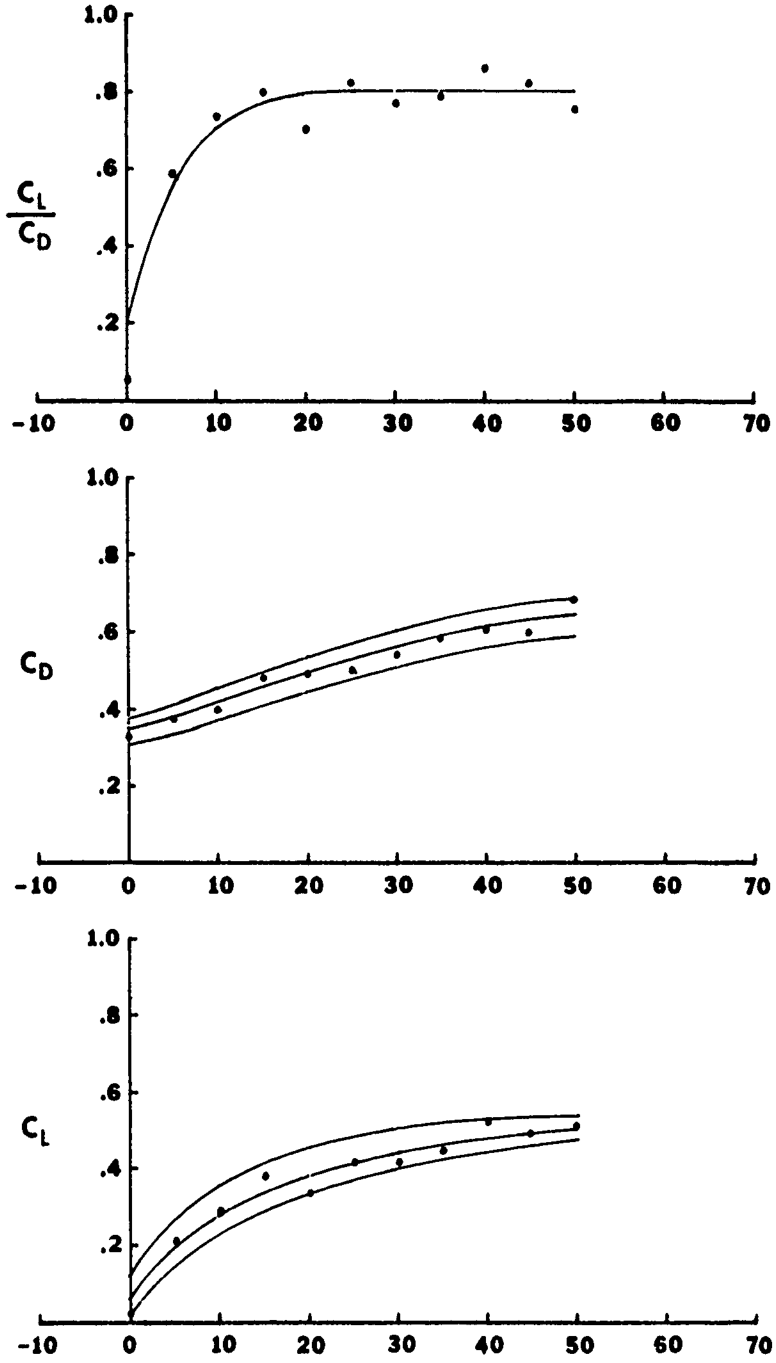
SUBJECT NO. 4

Figure 18 (d)



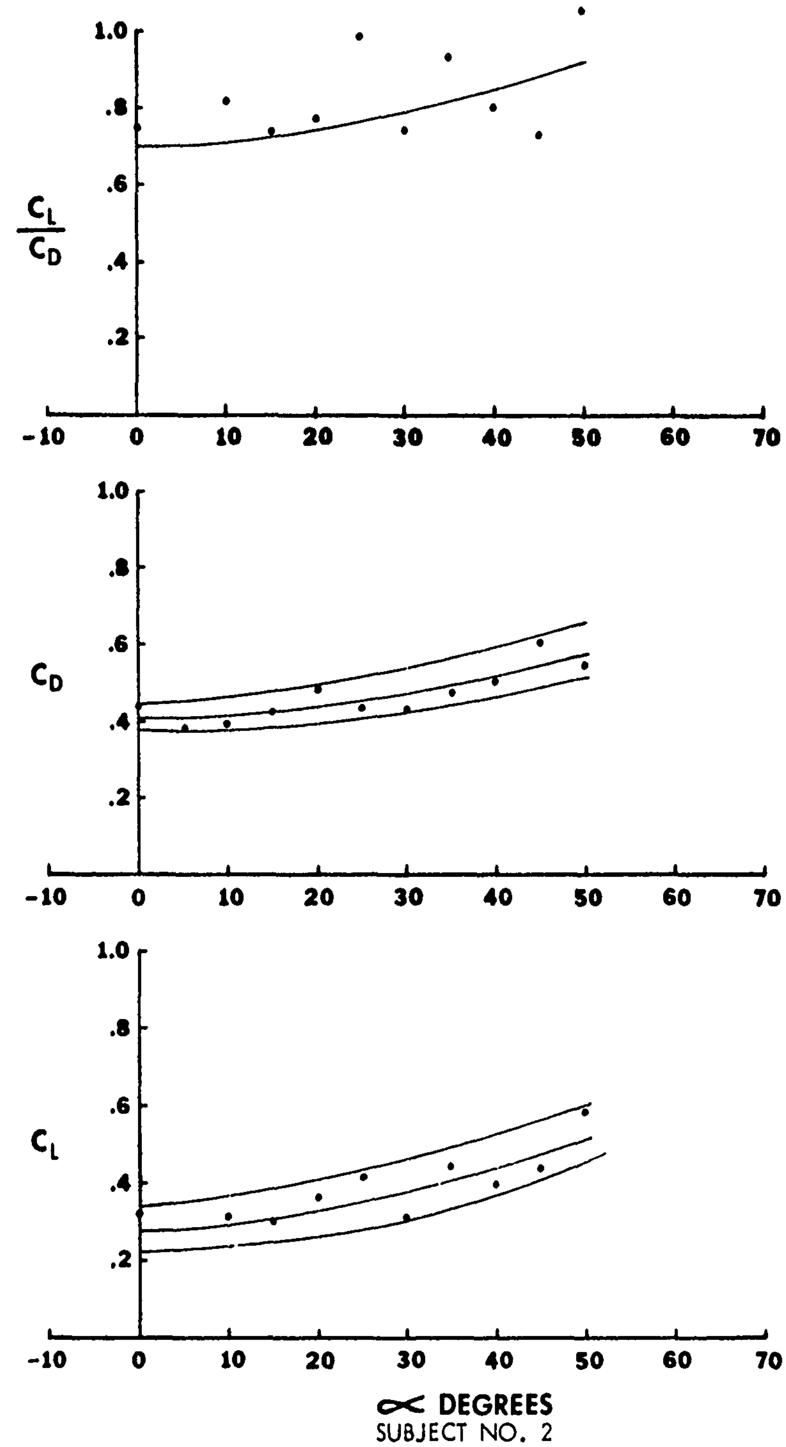
1.0
.8
.6
.4
.2
$\frac{C_L}{C_D}$
C_D
C_L
-10
0
10
20
30
40
50
60
70
∝ DEGREES
SUBJECT NO. 5

Figure 18 (e)



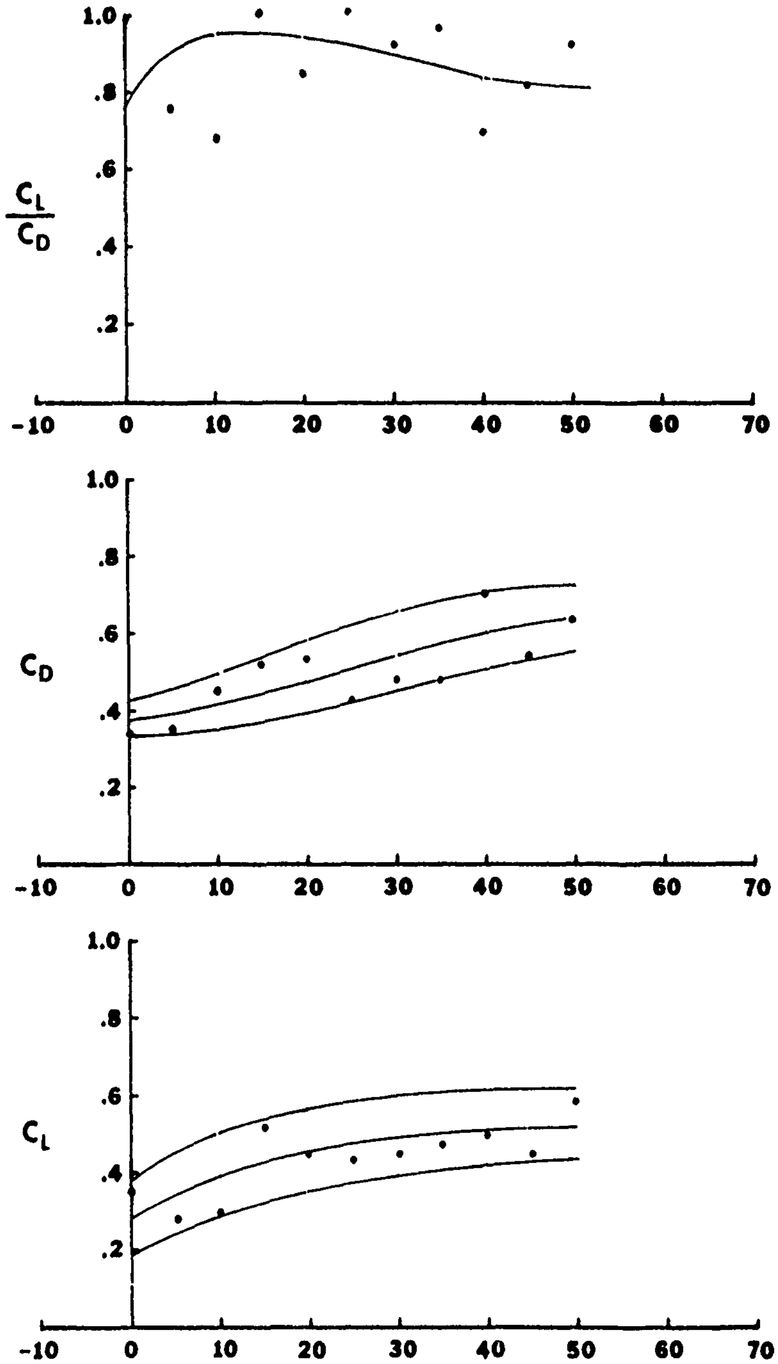
α DEGREES
PARACHUTE PACK CONFIGURATION NO. 4
SUBJECT NO. 1

Figure 19 (a)



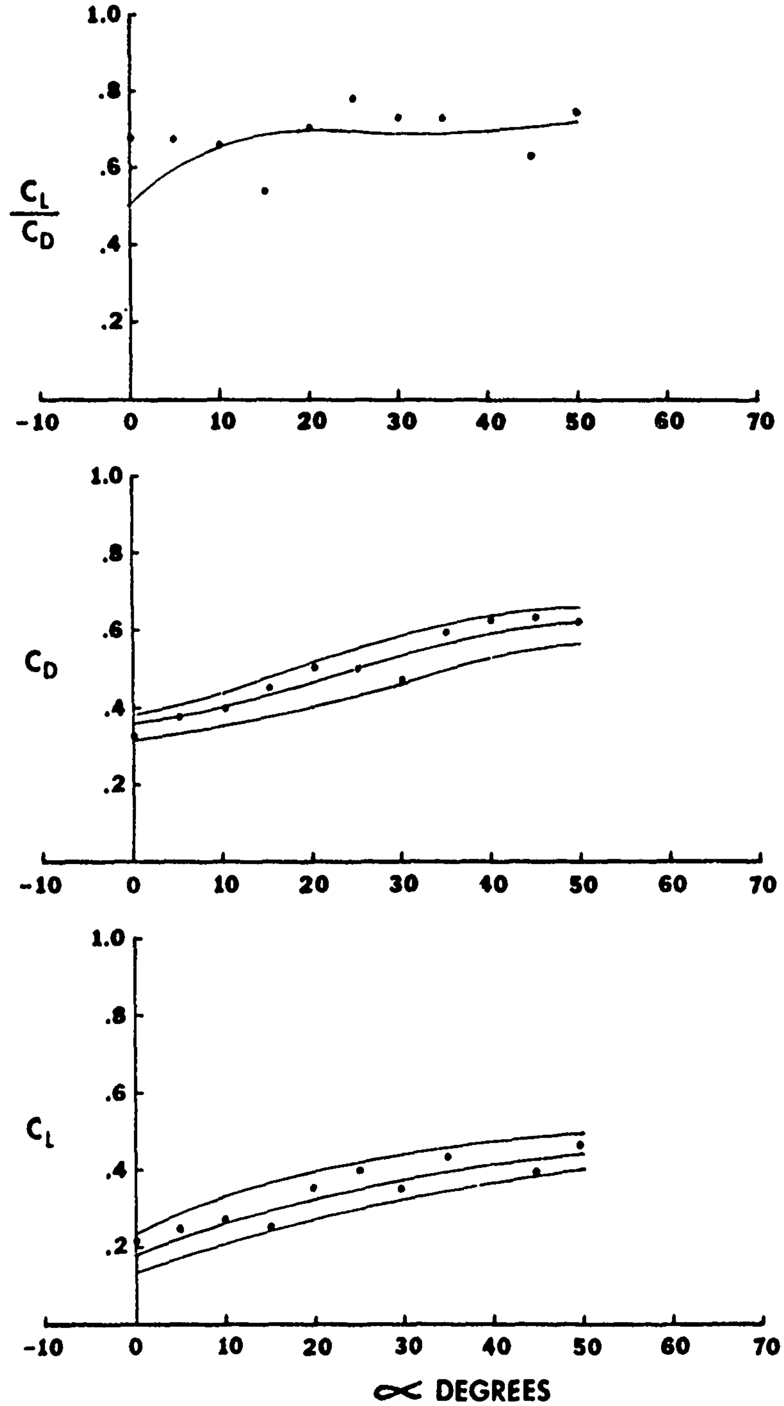
SUBJECT NO. 2

Figure 19 (b)



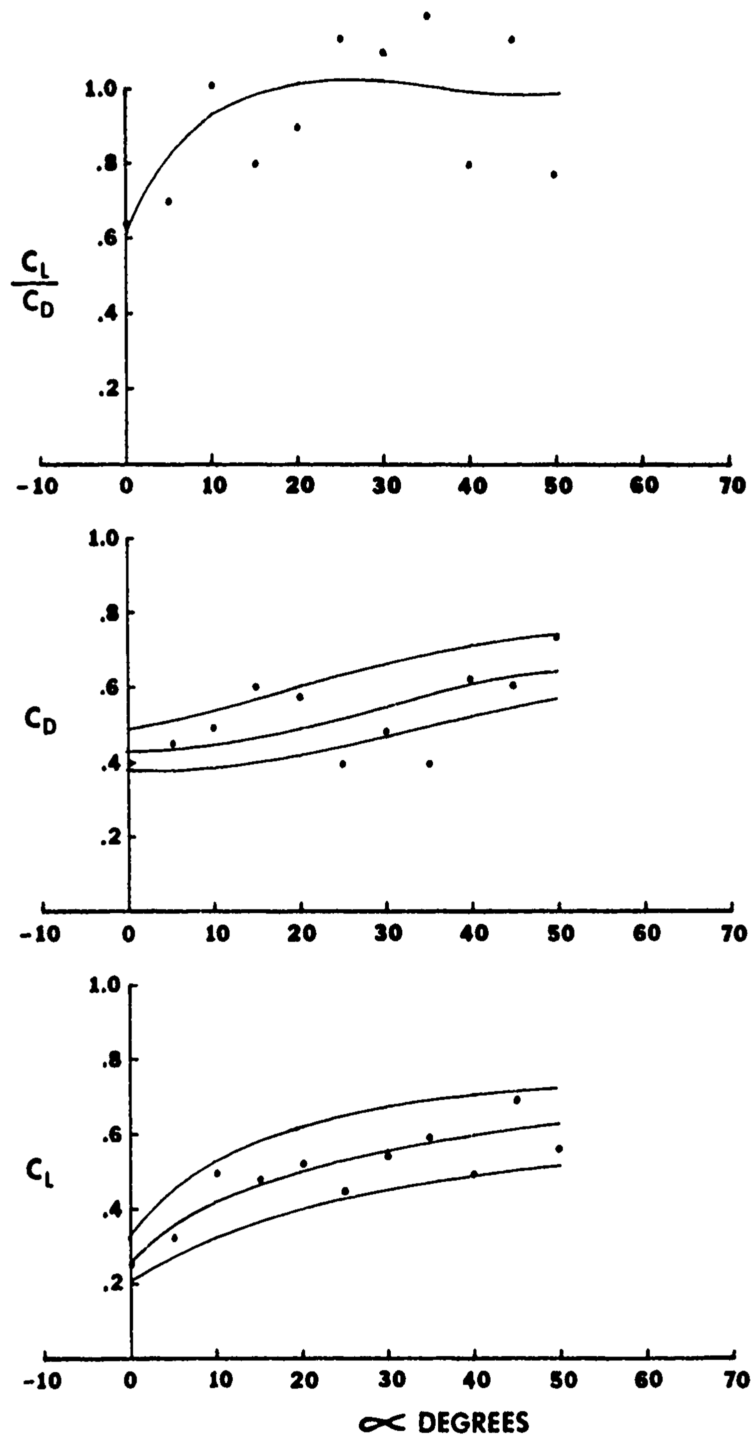
α DEGREES
SUBJECT NO. 3

Figure 19 (c)



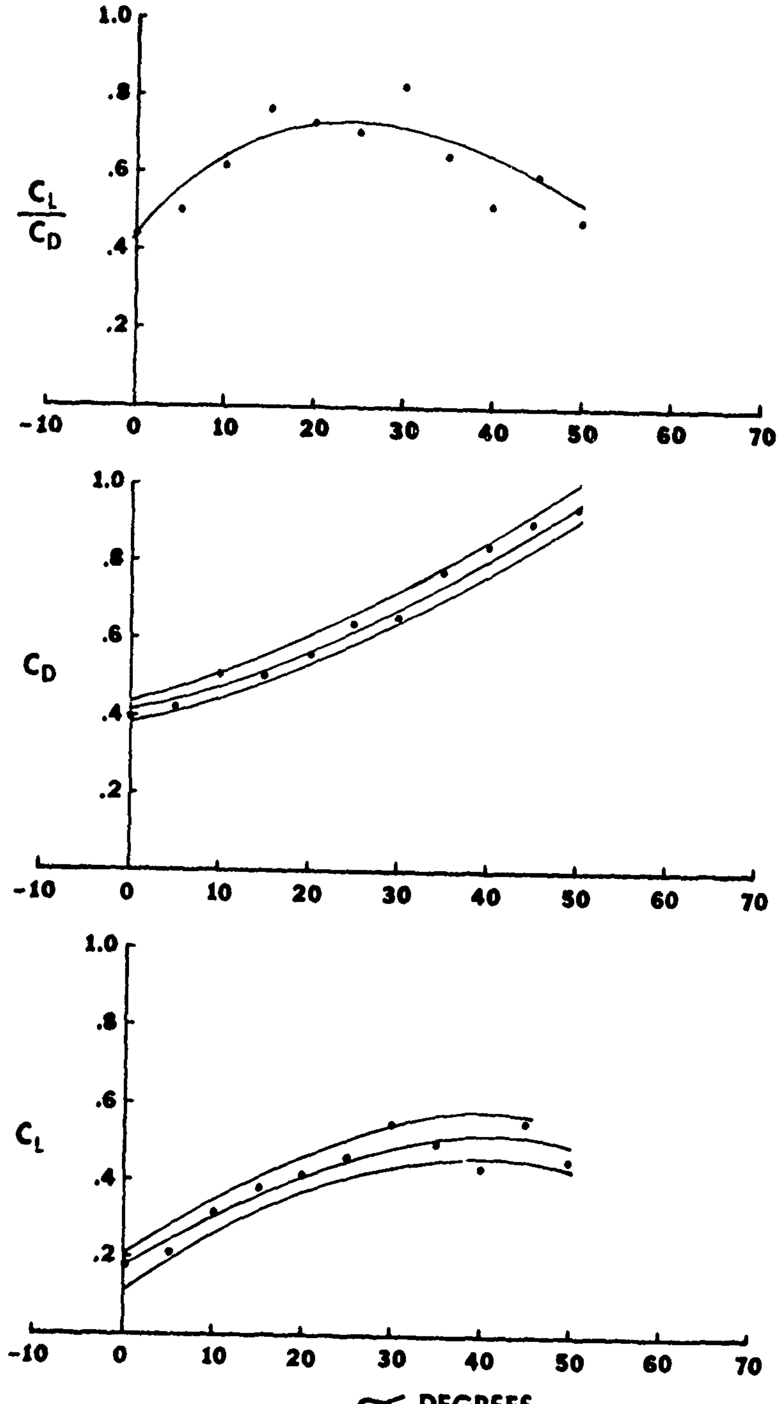
SUBJECT NO. 4

Figure 19 (d)



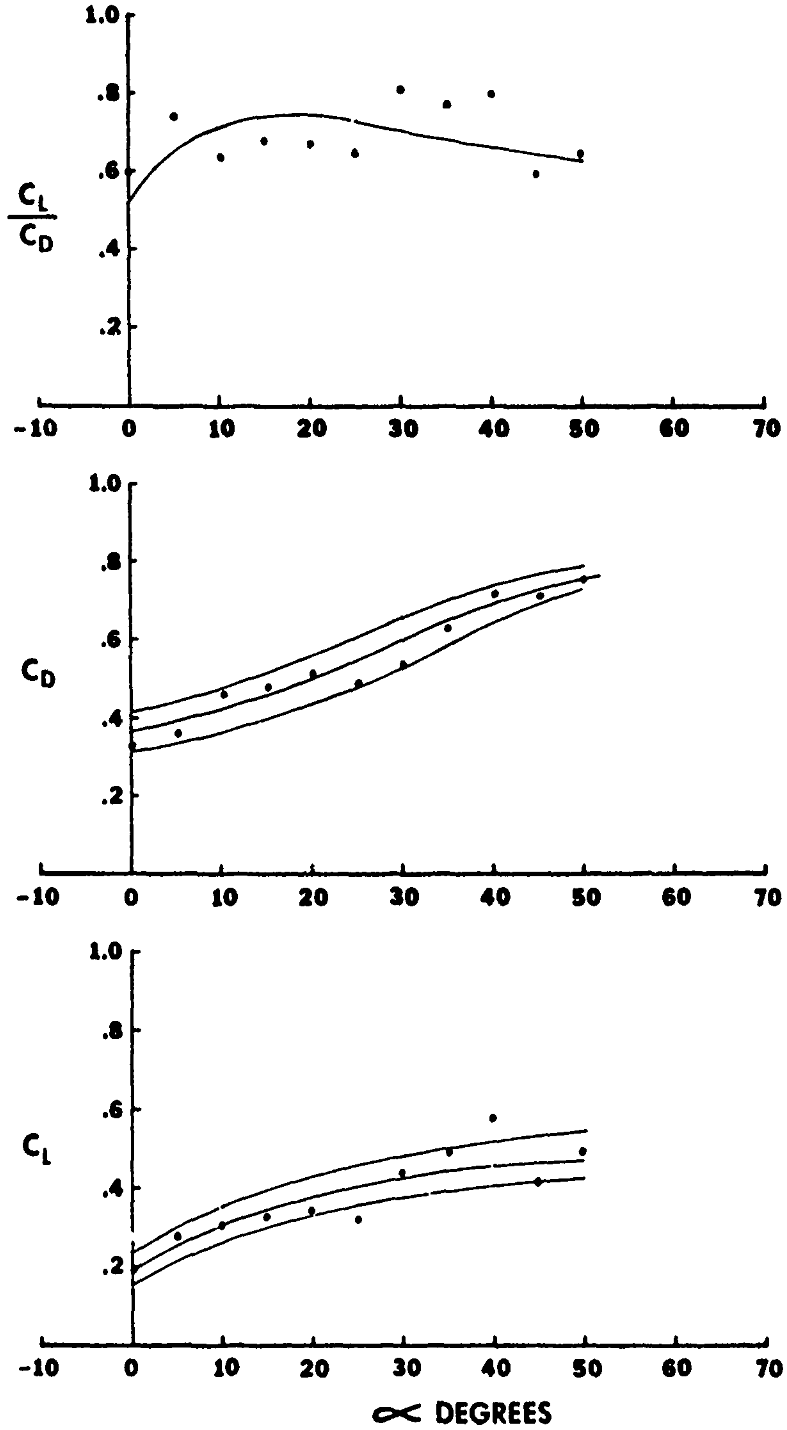
SUBJECT NO. 5

Figure 19 (e)



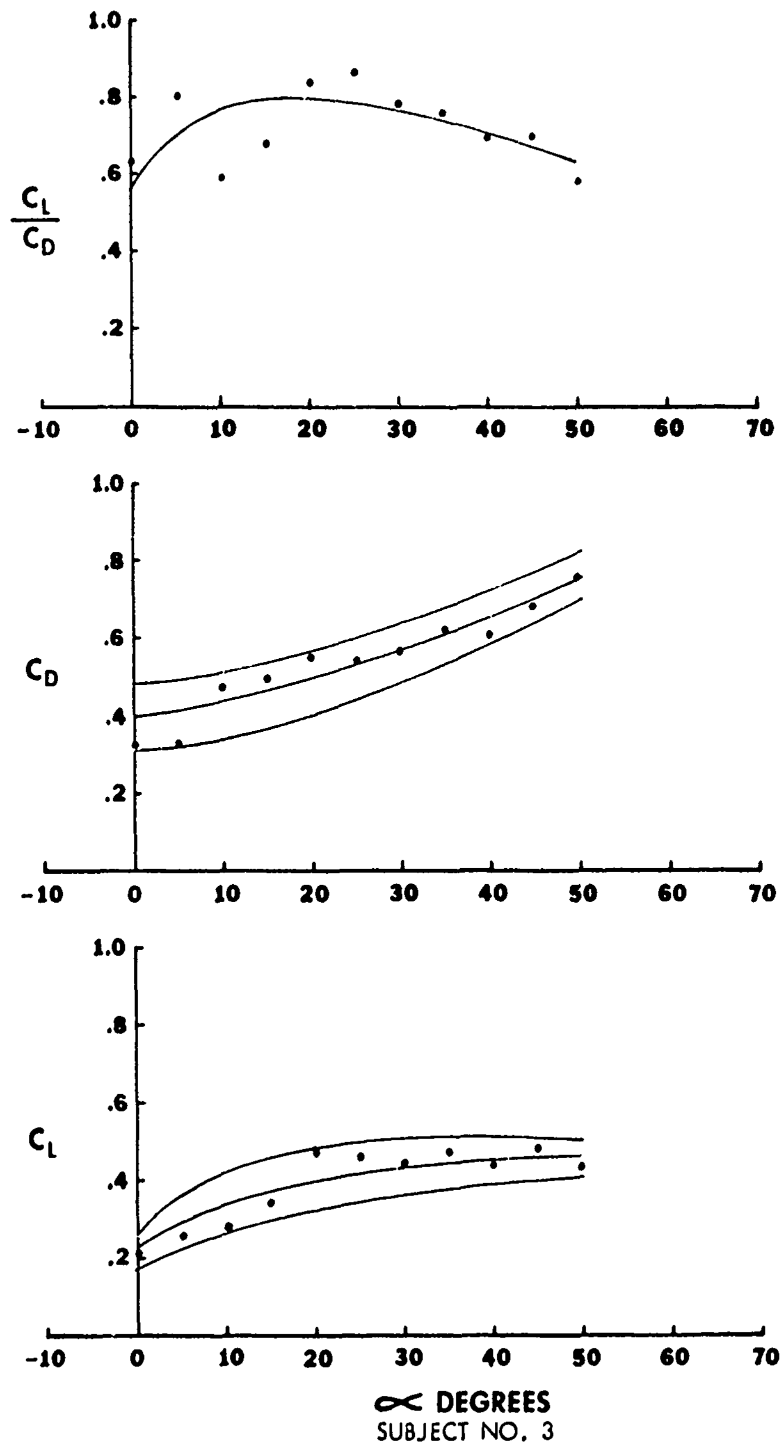
PARACHUTE PACK CONFIGURATION NO. 5
SUBJECT NO. 1

Figure 20 (a)



SUBJECT NO. 2

Figure 20 (b)



1.0
.8
.6
$\frac{C_L}{C_D}$
.4
.2
-10
0
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20
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70
1.0
.8
.6
C_D
.4
.2
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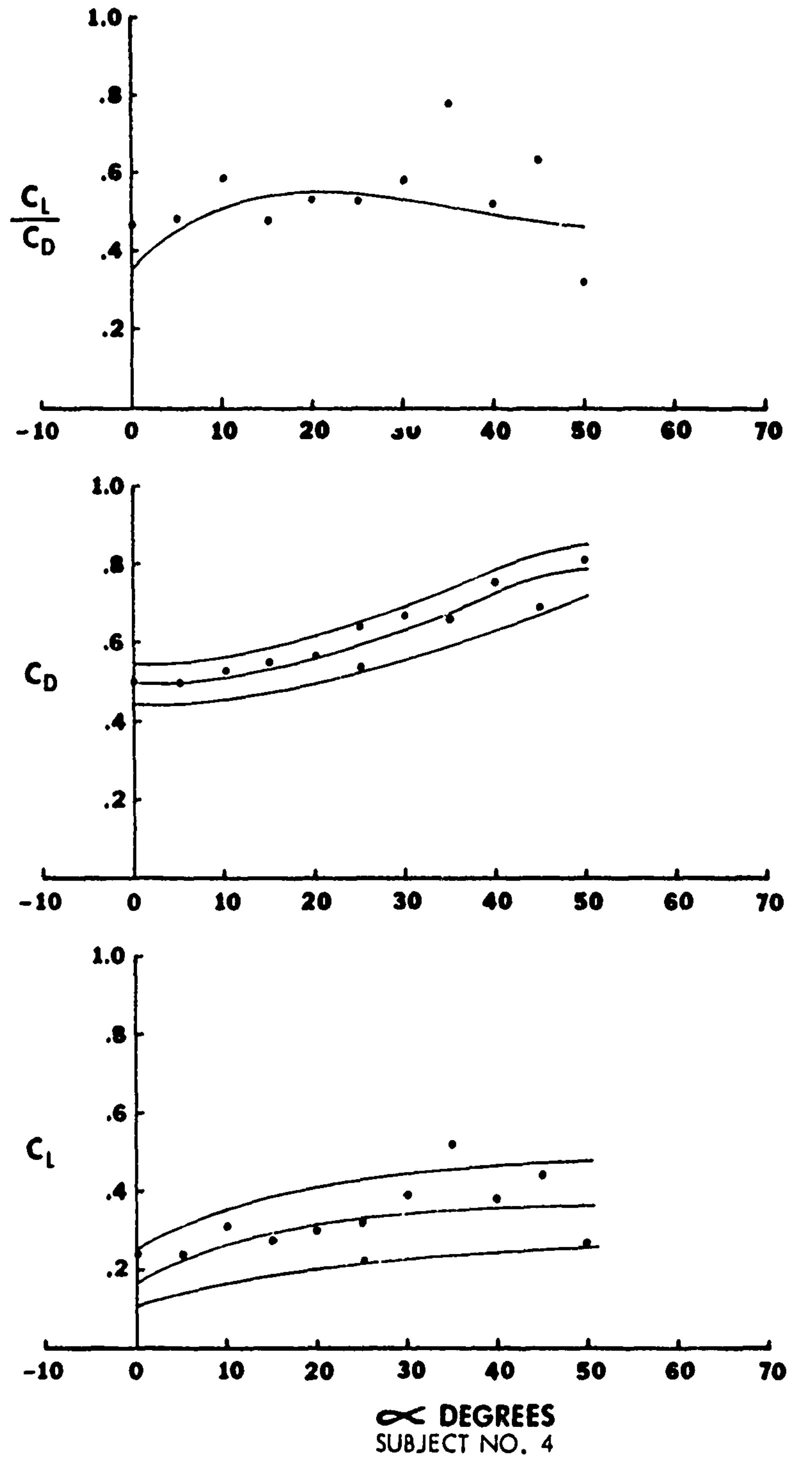
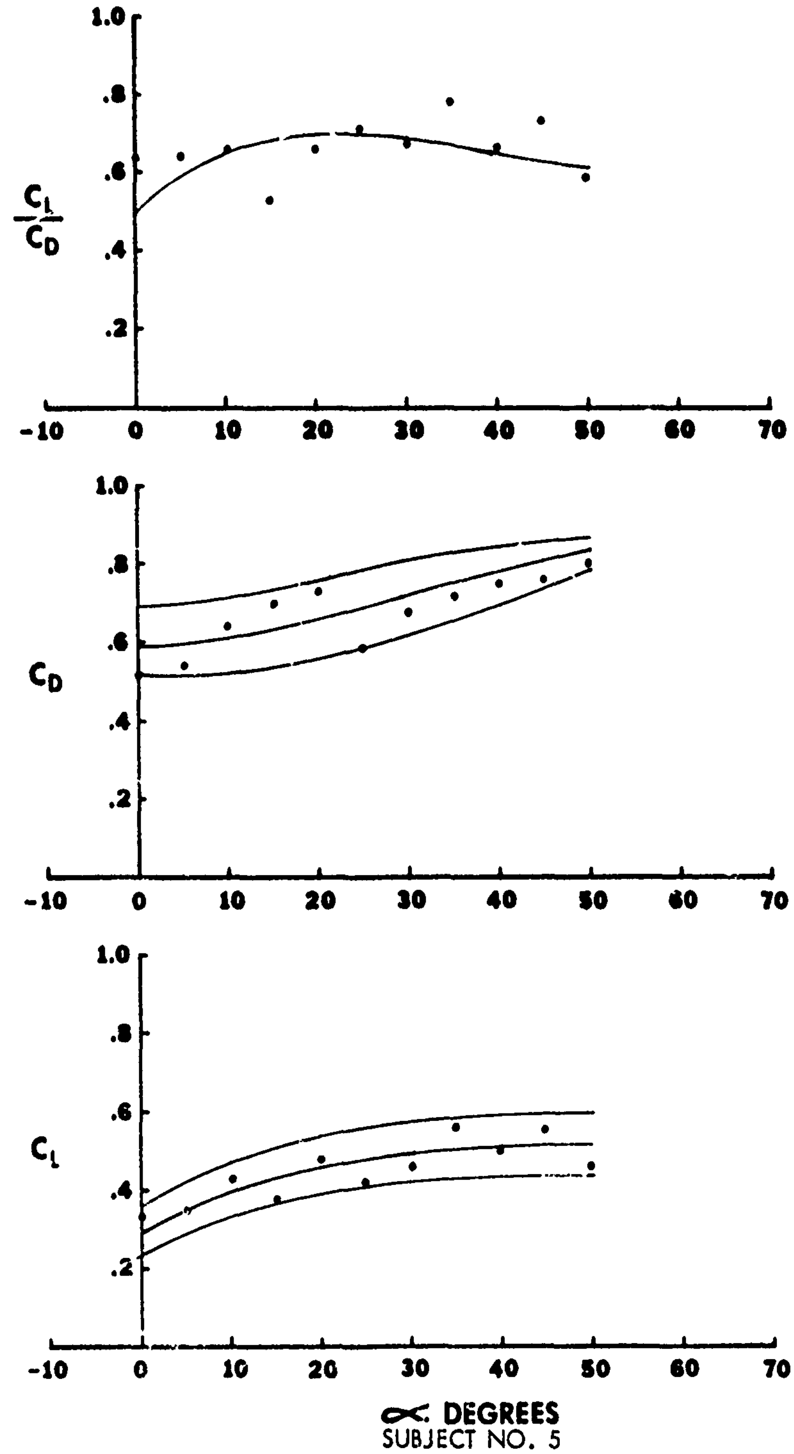
1.0
.8
.6
C_L
.4
.2
-10
0
10
20
30
40
50
60
70
α DEGREES
SUBJECT NO. 3

Figure 20 (c)



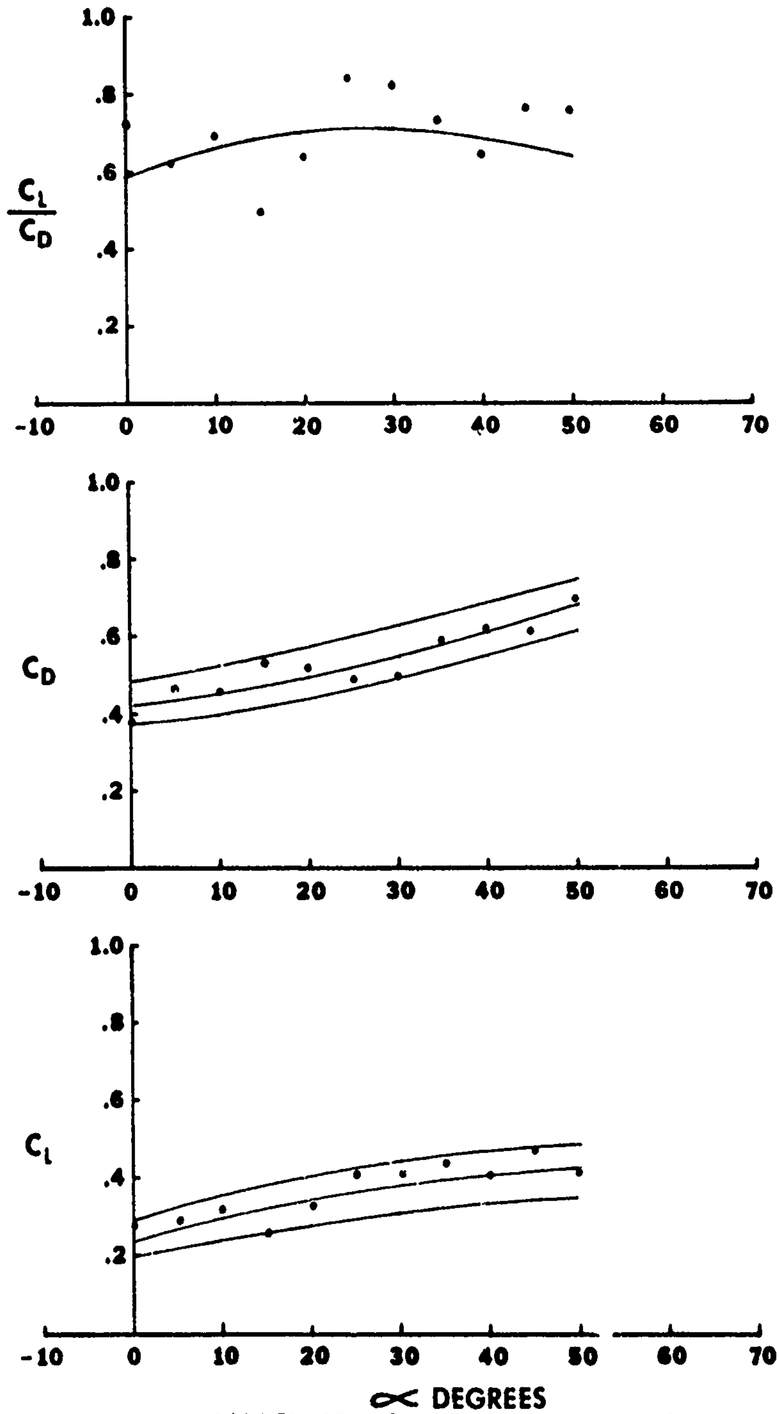
SUBJECT NO. 4

Figure 20 (d)



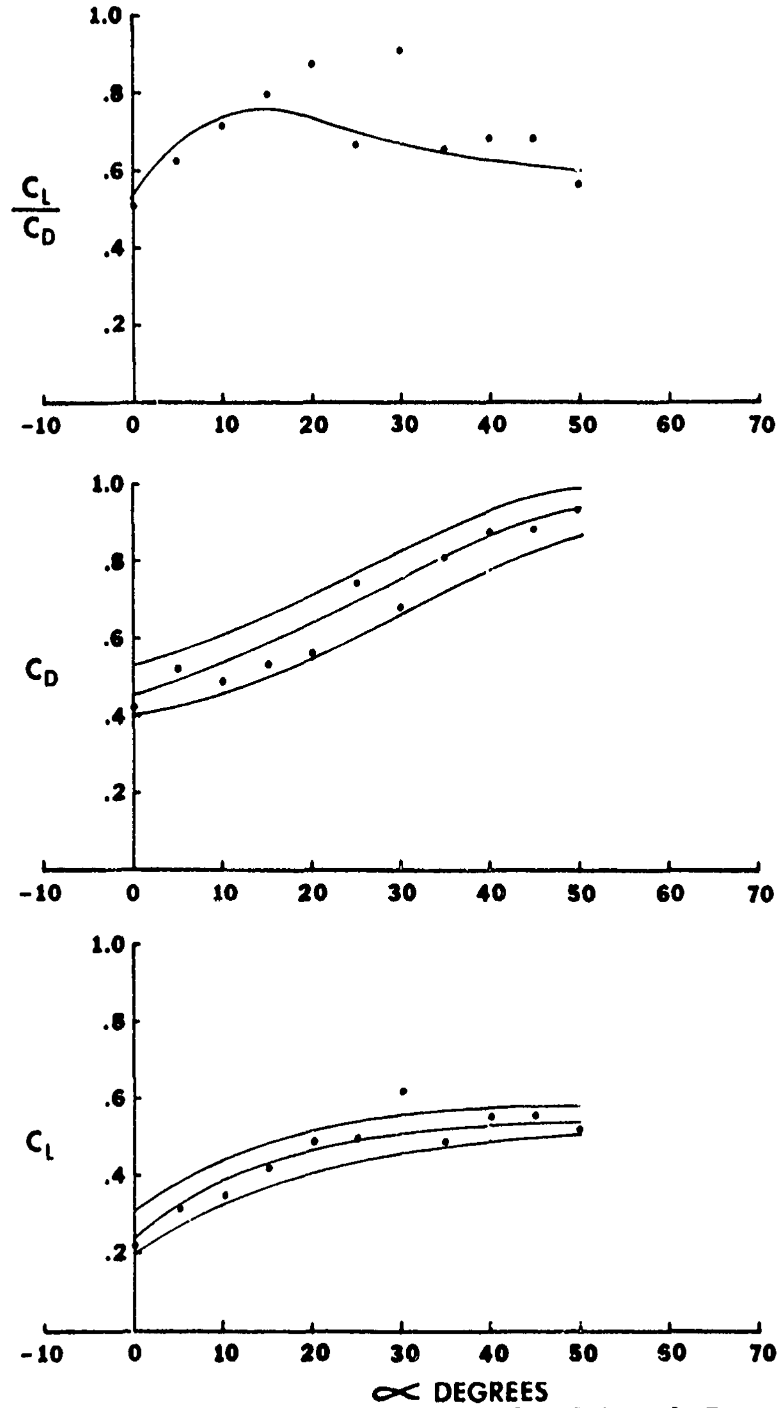
SUBJECT NO. 5

Figure 20 (e)



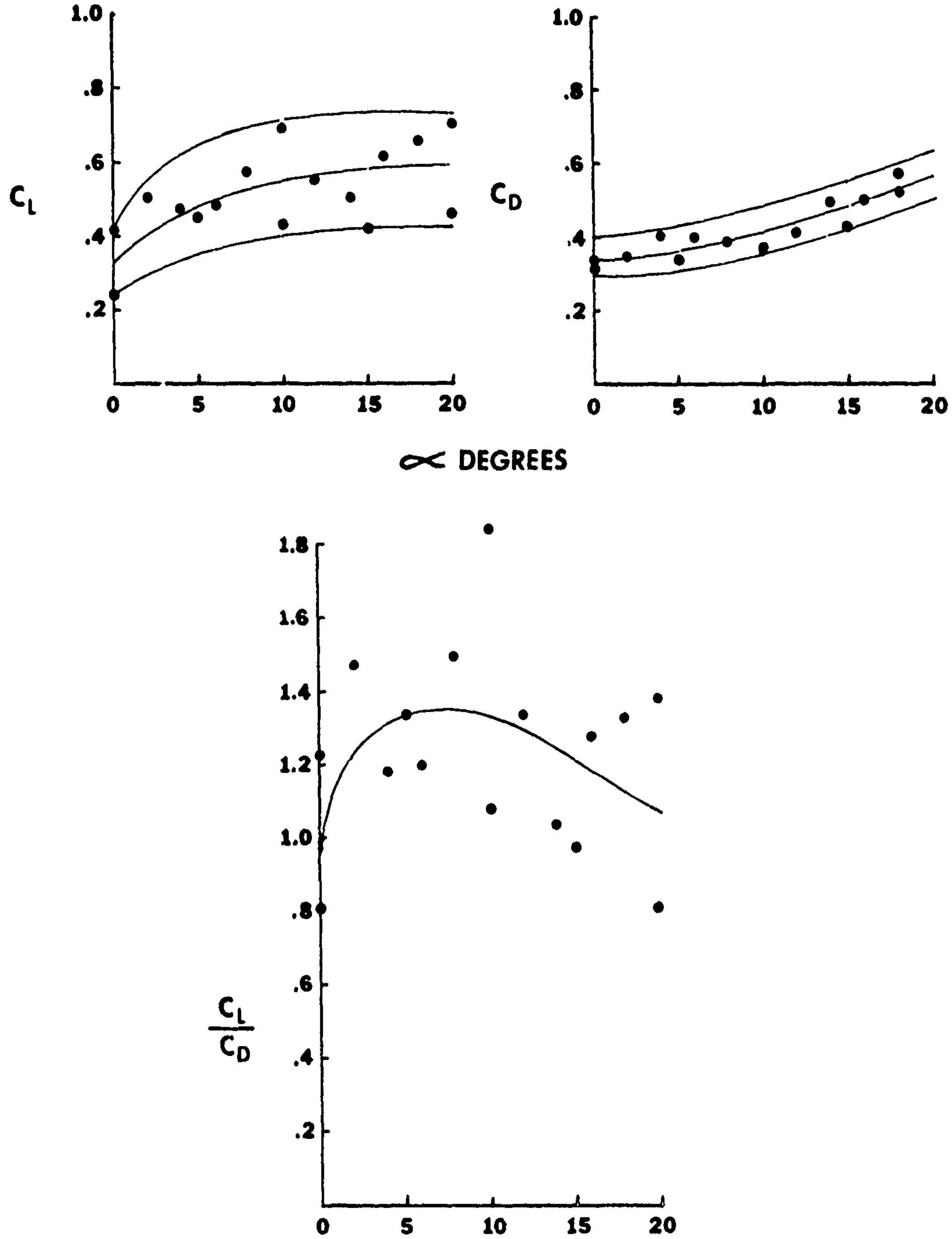
PARACHUTE PACK CONFIGURATION NO. 6
SUBJECT NO. 2

Figure 21



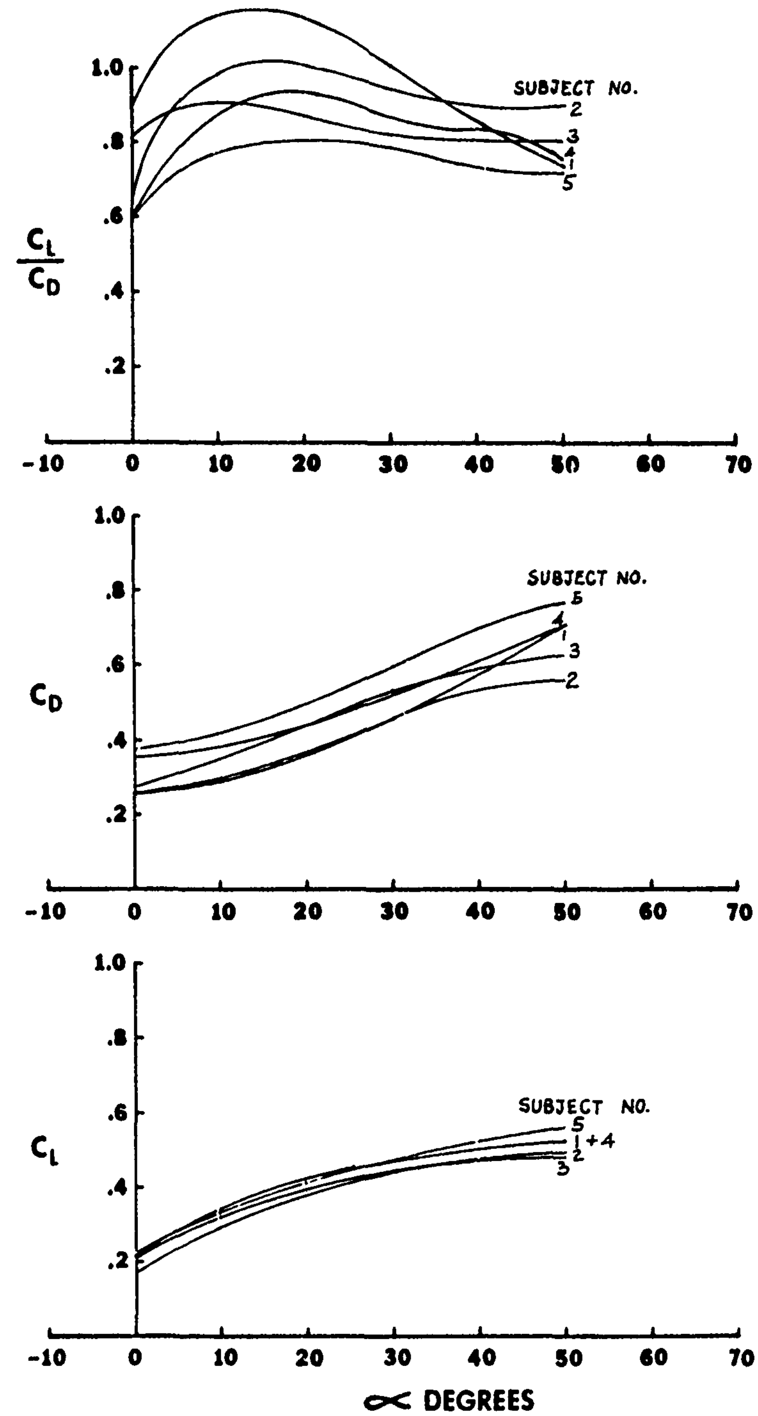
PARACHUTE PACK CONFIGURATION NO. 7
SUBJECT NO. 5

Figure 22



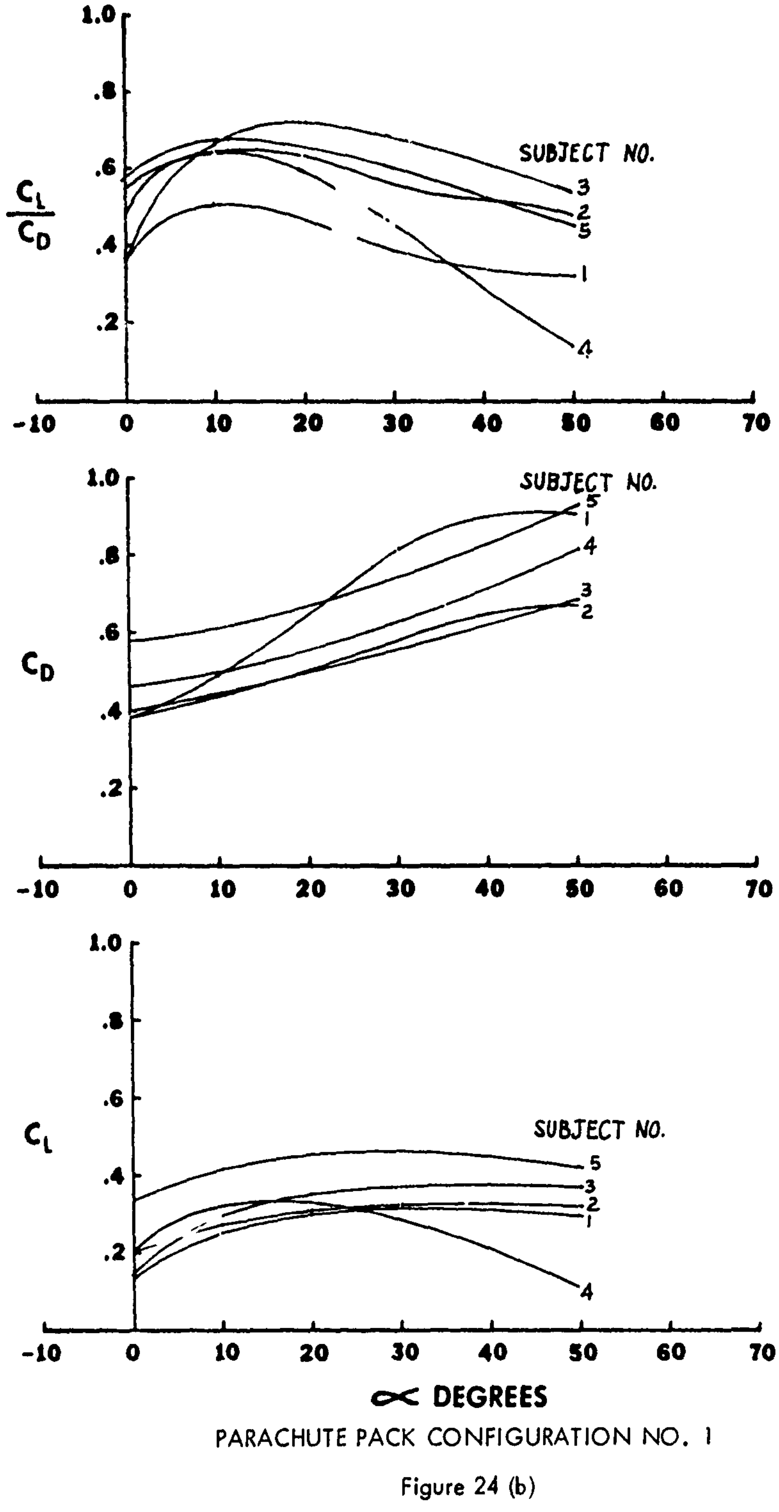
PARACHUTE PACK CONFIGURATION NO. 8
SUBJECT NO. 1

Figure 23



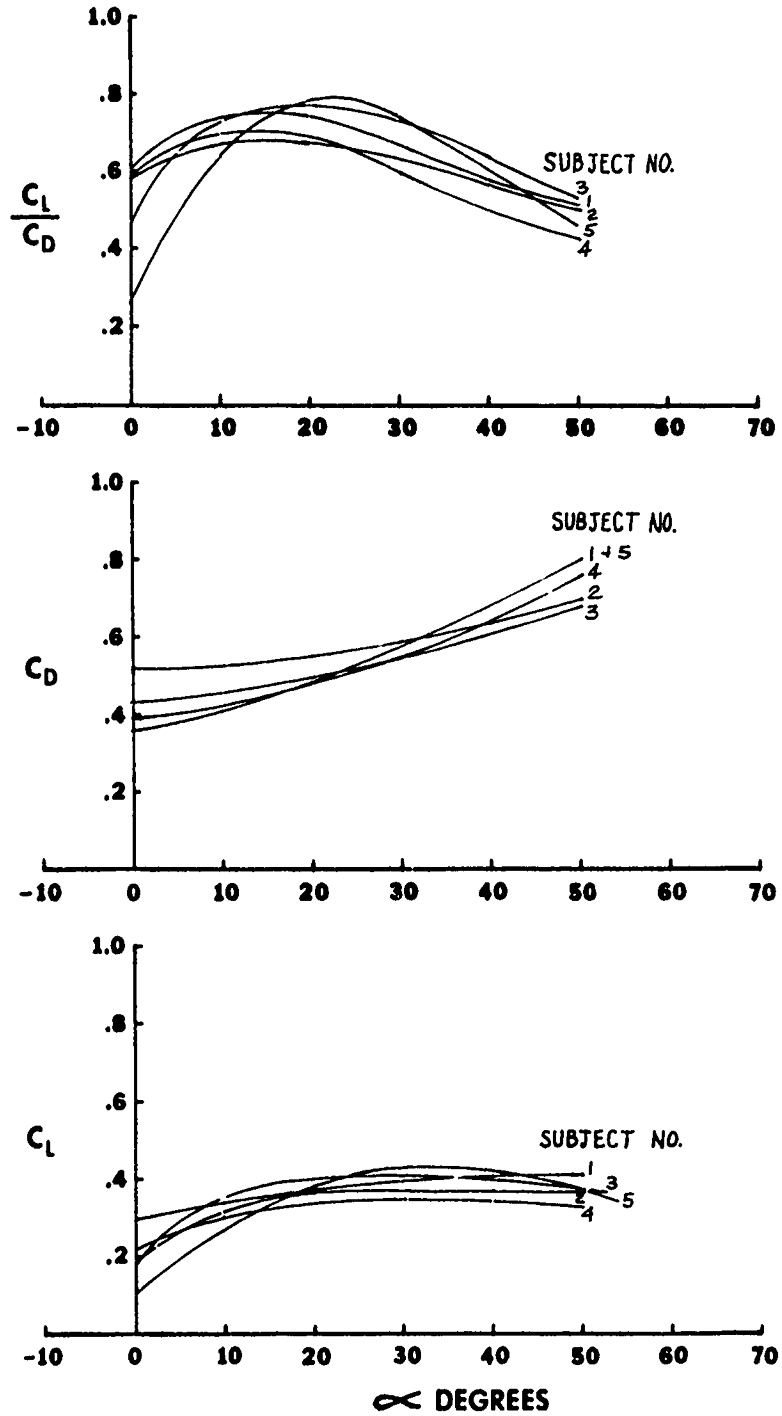
PARACHUTE PACK CONFIGURATION NO. 0

Figure 24 (a)



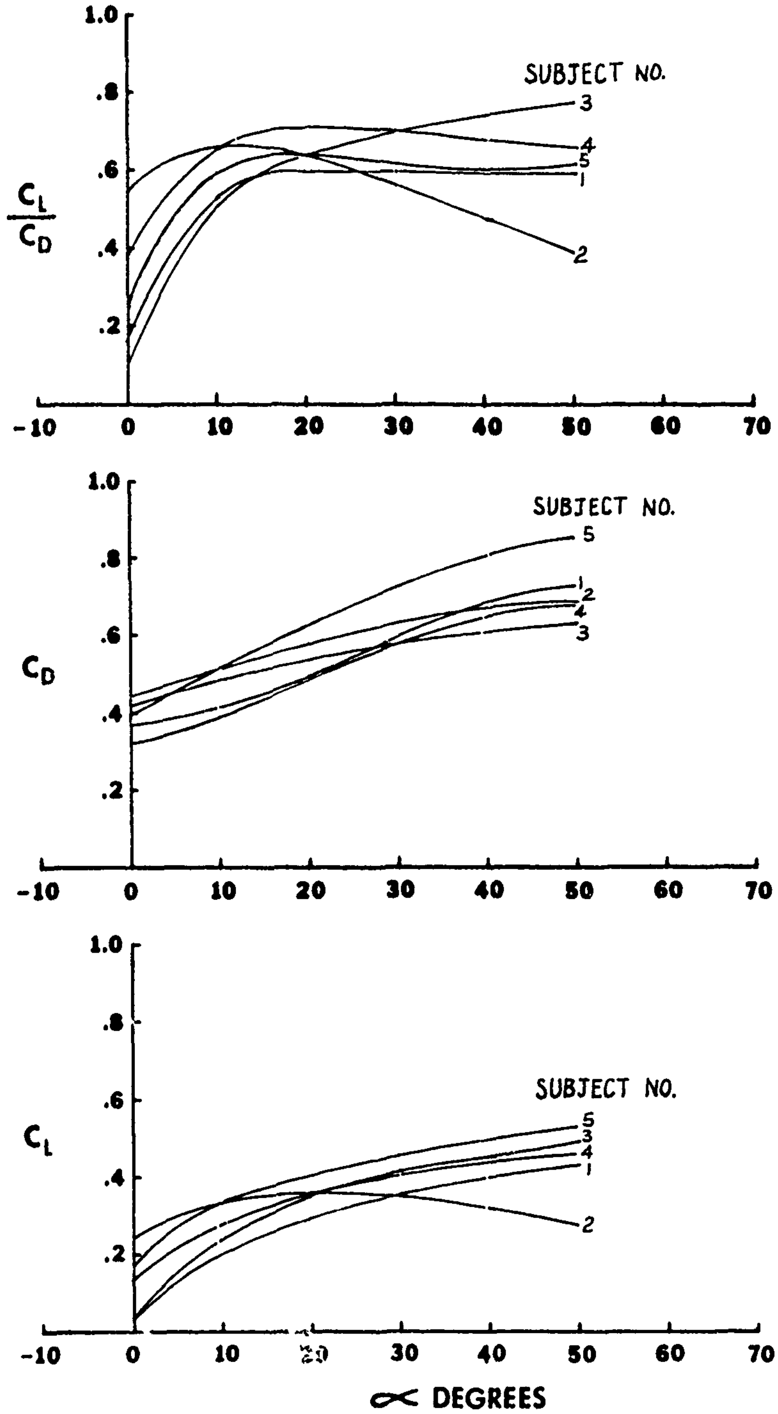
PARACHUTE PACK CONFIGURATION NO. 1

Figure 24 (b)



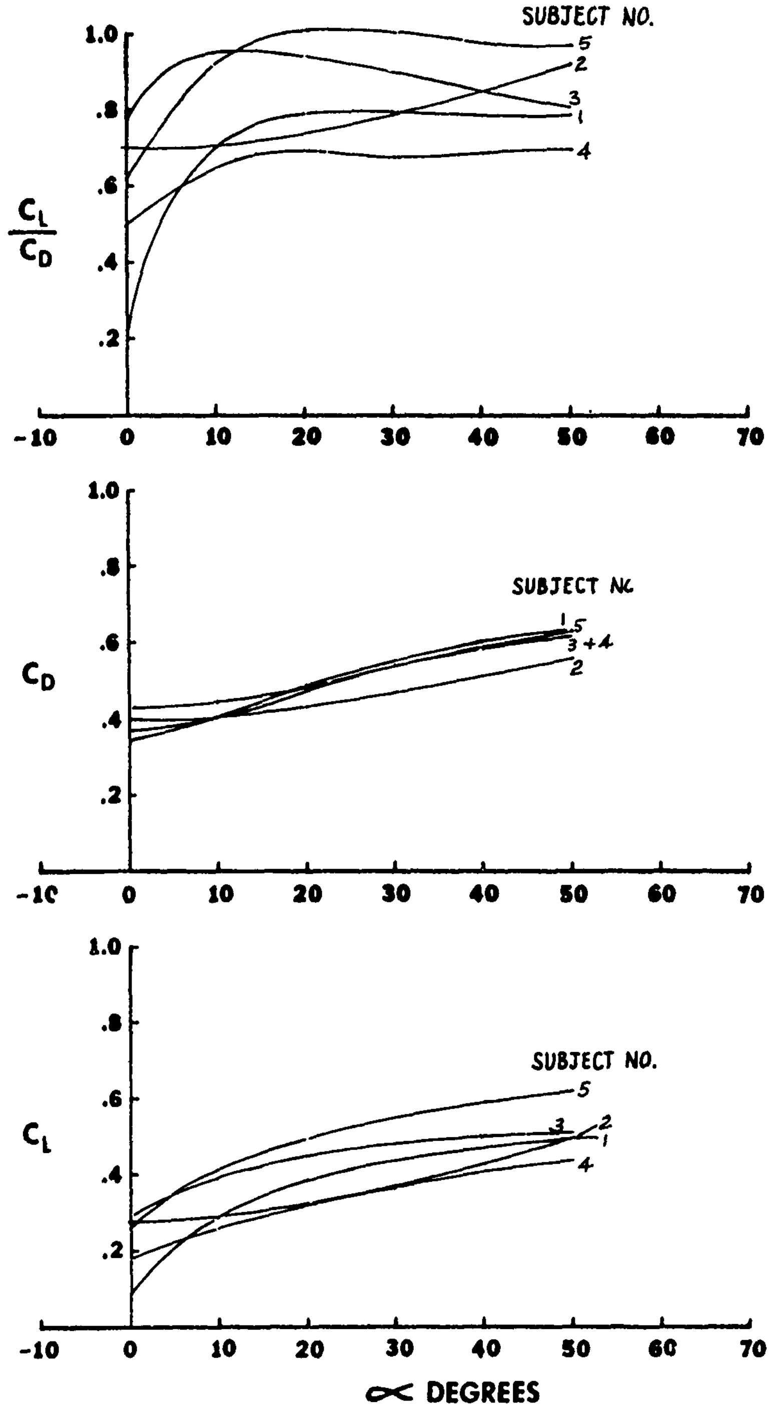
PARACHUTE PACK CONFIGURATION NO. 2

Figure 24 (c)



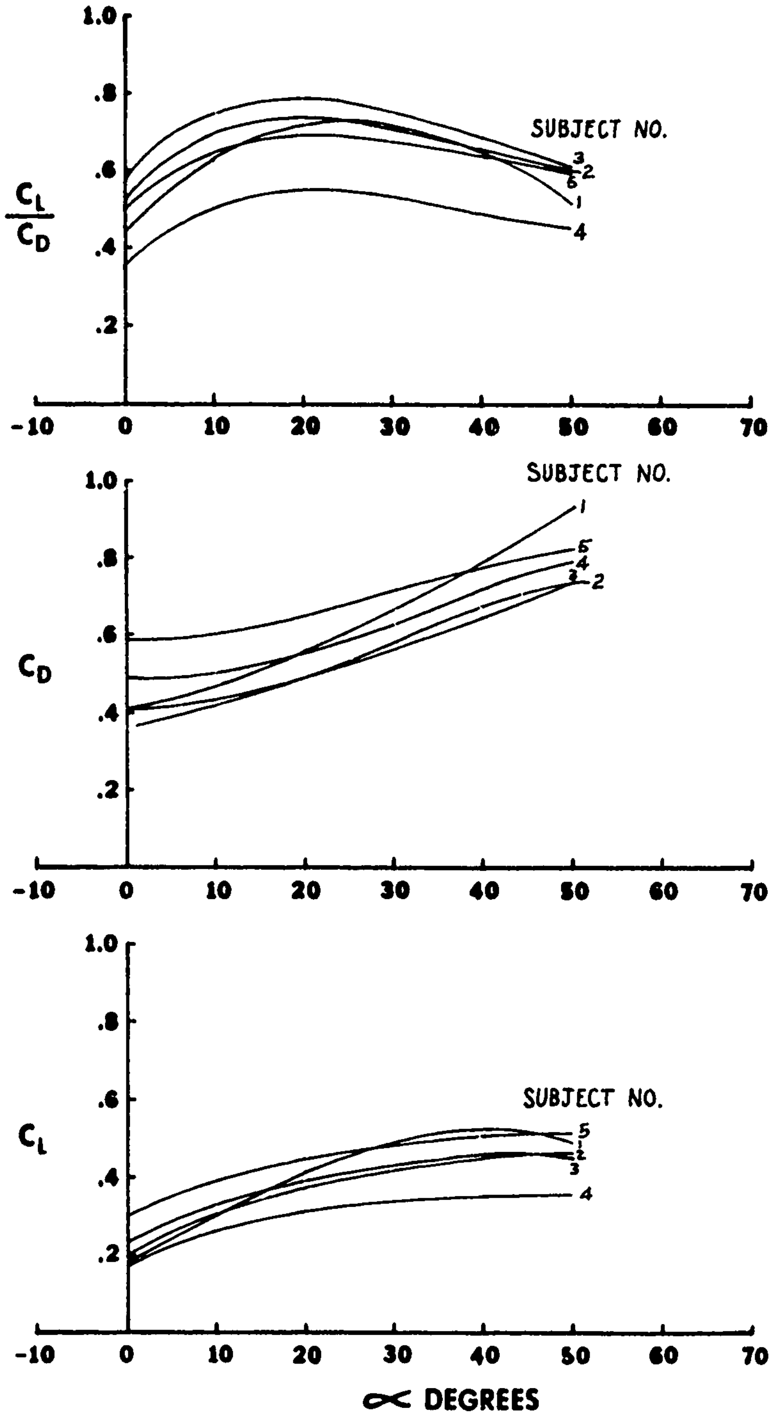
PARACHUTE PACK CONFIGURATION NO. 3

Figure 24 (d)



PARACHUTE PACK CONFIGURATION NO. 4

Figure 24 (e)



PARACHUTE PACK CONFIGURATION NO. 5

Figure 24 (f)

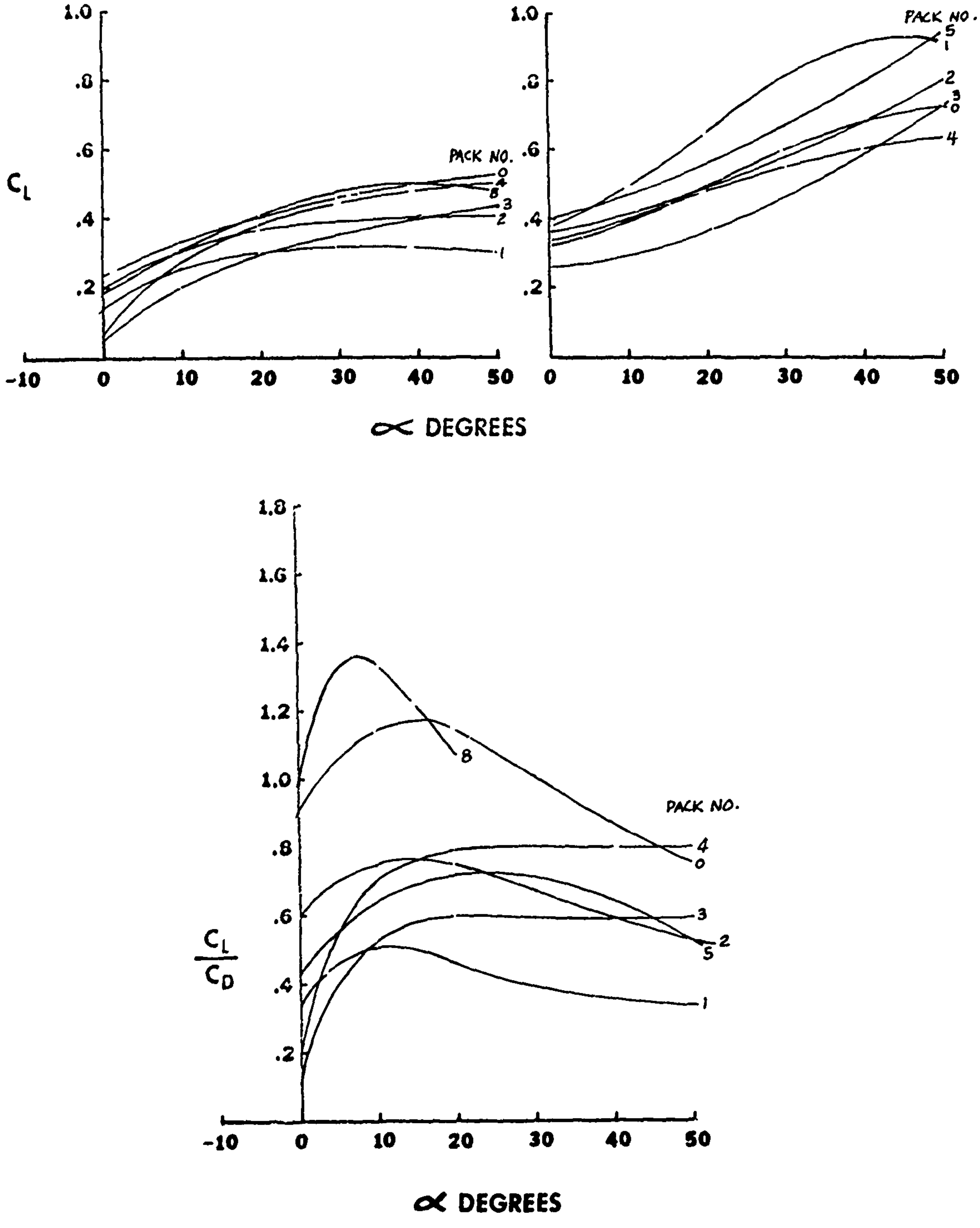


Figure 25 (a), SUBJECT NO. 1

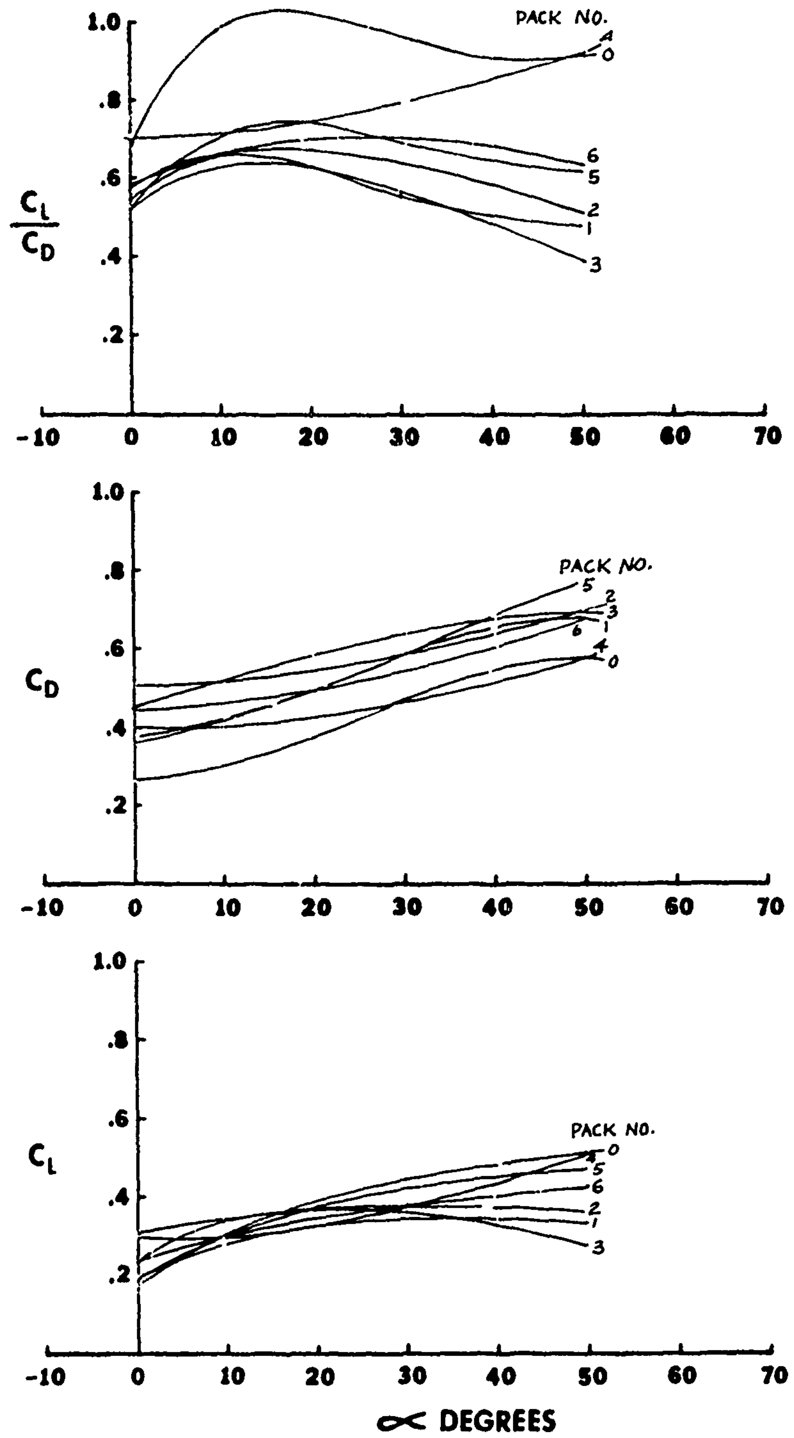


Figure 25 (b) ,SUBJECT NO. 2

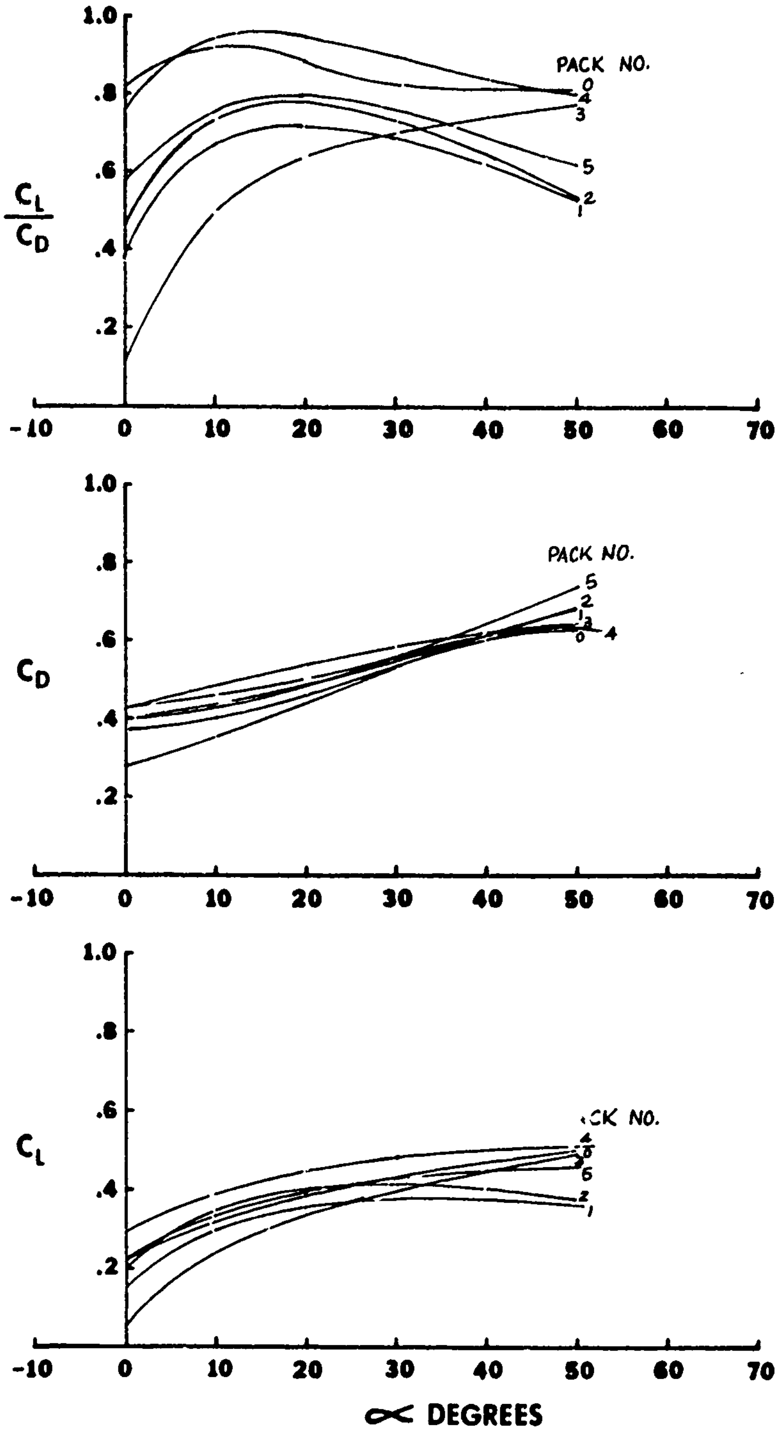


Figure 25 (c), SUBJECT NO. 3

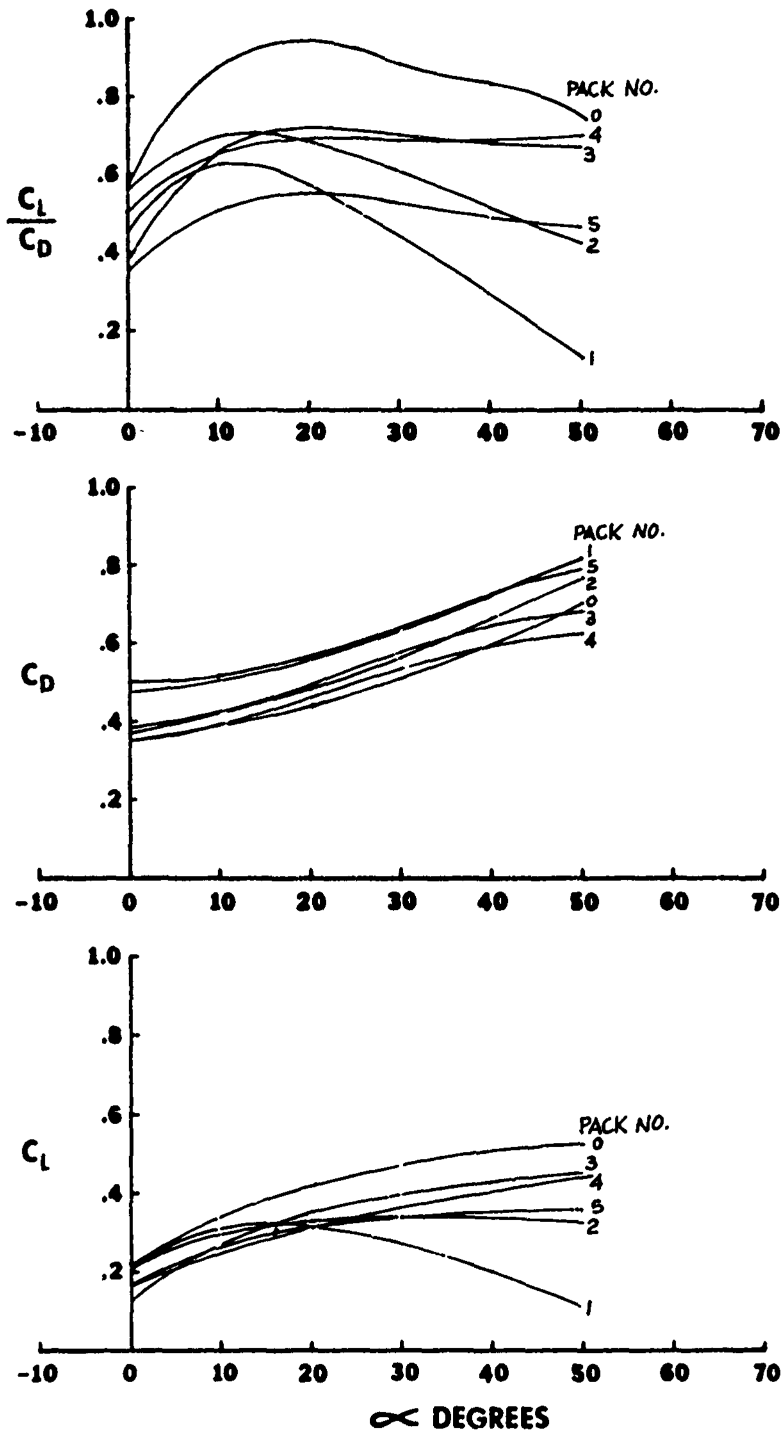


Figure 25 (d), SUBJECT NO. 4

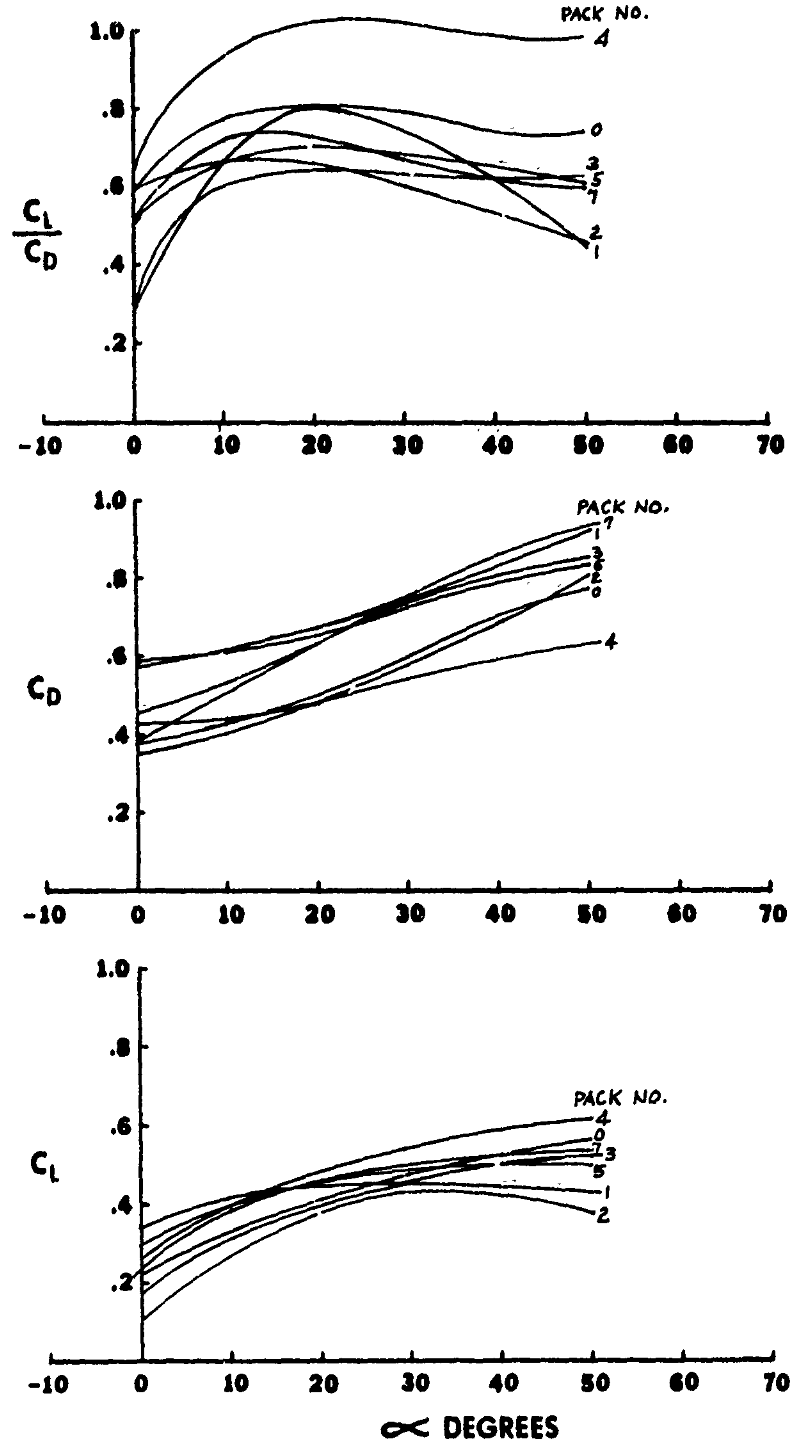


Figure 25 (e), SUBJECT NO. 5

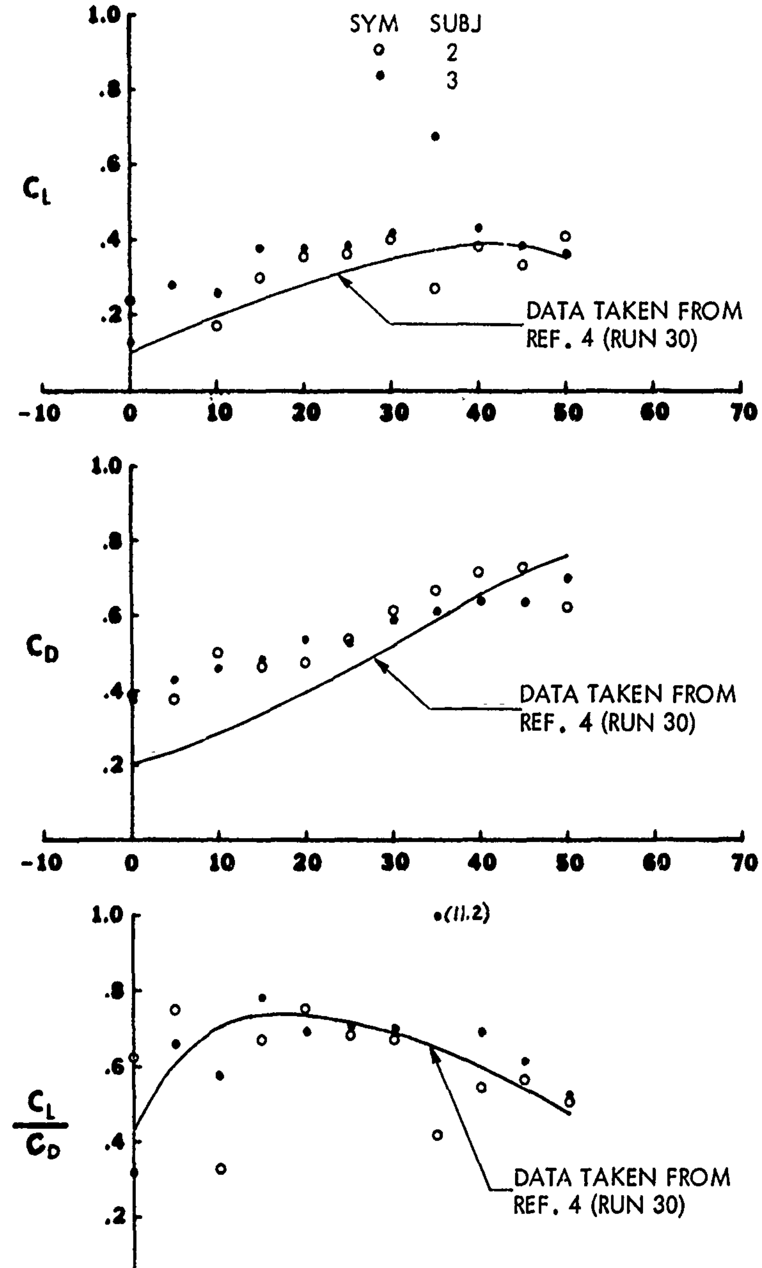


Figure 26 (a)

COMPARISON OF DATA OBTAINED FROM
LIVE SUBJECTS AND AN ANTHROPOMORPHIC DUMMY
(a) BODY CONFIGURATION "A"

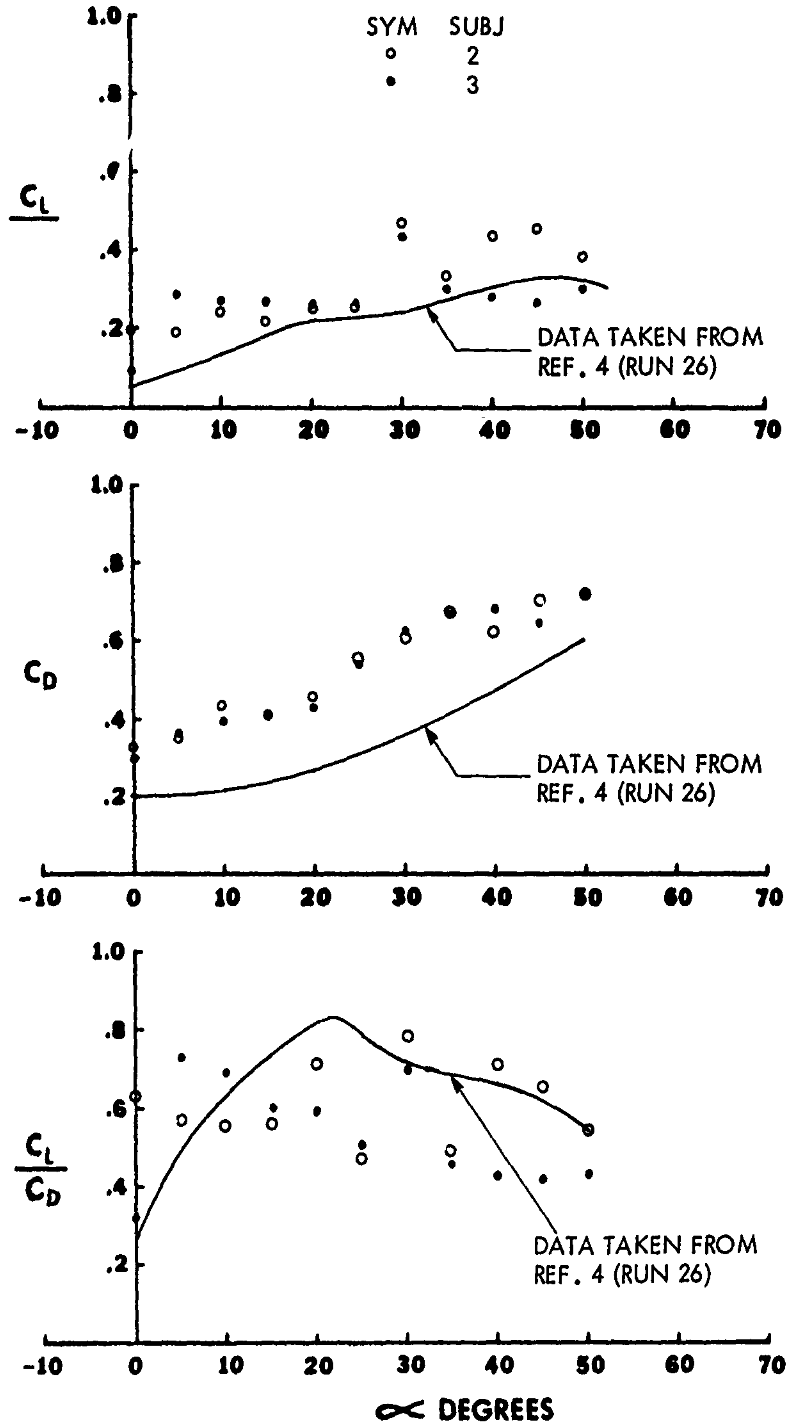
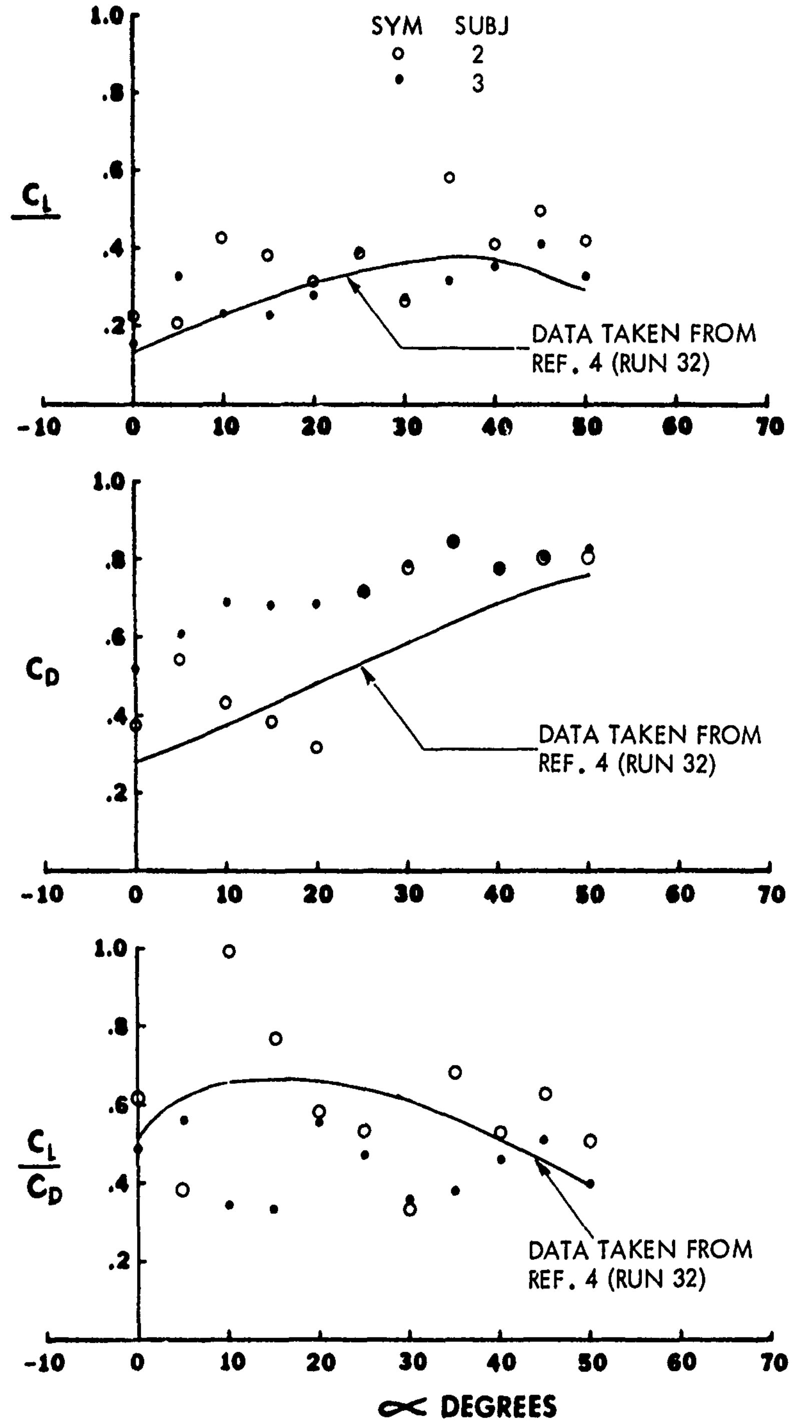

SYM SUBJ
2
3
C_L
DATA TAKEN FROM REF. 4 (RUN 26)
C_D
DATA TAKEN FROM REF. 4 (RUN 26)
$\frac{C_L}{C_D}$
DATA TAKEN FROM REF. 4 (RUN 26)
∝ DEGREES

Figure 26 (b)



SYM SUBJ
○ 2
• 3
C_L
DATA TAKEN FROM REF. 4 (RUN 32)
C_D
DATA TAKEN FROM REF. 4 (RUN 32)
$\frac{C_L}{C_D}$
DATA TAKEN FROM REF. 4 (RUN 32)
α DEGREES

Figure 26 (c)

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13. ABSTRACT

Five subjects were used to determine the lift and drag characteristics of the human body held in a tracking attitude. The effects of eight different parachute pack configurations were tested to evaluate the influence of the pack upon lift and drag.

1. The mean C_L of our unencumbered subjects (0.374) corresponded to the C_L attributed to Straumann's ski-jumpers (0.43).
2. Changes in parachute pack configuration significantly changed L/D, C_L, and C_D. Subjects appeared to be homogeneous.
3. Design of a pack tray is described which, by test, had a significantly higher L/D than any currently available parachute pack tray configuration.
4. Man is not an ideal subject to test as an airfoil in the wind tunnel.

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